1946

Biology and control of the tuber flea beetle, Epitrix tuberis Gentner, in Nebraska

Roscoe Earle Hill
Iowa State College

BIOLOGY AND CONTROL OF THE TUBER FLEA BEETLE,

Epitrix tuberis Gentner, IN NEBRASKA

by

Roscoe Earle Hill

A Thesis Submitted to the Graduate Faculty

for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Entomology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State College

1946

TABLE OF CONTENTS

INTRODUCTION

Introductory Statement

Flea beetles are the most important of the insect pests found on potatoes in western Nebraska, especially in the irrigated sections of the North Platte Valley. Tuber blemishes caused by the larvae of the tuber flea beetle, *Epitrix tuberis* Gentner, are major factors in lowering the quality of the crop. In many instances potatoes which otherwise would grade as U. S. No. 1 must be sold as U. S. No. 2 or "culls" because of this insect injury.

About 1938 western Nebraska potato growers began to experience increased difficulty in controlling flea beetles. It became evident that the control methods then being followed were not satisfactory. Furthermore, in 1938, severe losses were suffered throughout the state from an unprecedented outbreak of the potato psyllid, *Paratrioza cockerelli* (Sulc). Obviously there was need for additional research.

As a result of demands from western Nebraska potato producers, a special appropriation was voted by the 1939 session of the Nebraska Unicameral for the purpose of instigating further investigations on the control of potato insects. Subsequently, in 1940, an Experiment Station project was set up for this purpose and the writer was appointed to conduct the field work. Since then, and for the past seven seasons, he has devoted a major share of his time to that project. With respect to the tuber flea beetle, the investigations followed two lines; first, a study was made of the biology and ecology of the species, and second, field experiments were conducted involving the testing of various insecticides and methods of application. The results obtained form the substance of the present dissertation.

Systematic Status and General Distribution

The flea beetle, *Epitrix tuberis* Gentner (Order Coleoptera, Family Chrysomelidae), was described as a new species in July, 1944 (27). Entomologists previously had been including this form under the name *E. cucumeris* (Harris). However, for a long time it has been known that in certain western areas the principal flea beetle injury to potatoes is caused by the larvae feeding on the tubers, whereas in the eastern states a major portion of the damage results from reduced yields following extensive foliage injury by the adults.

After an intensive study of the black species of the genus *Epitrix*, Gentner (27) described the common form occurring in the western states as new and proposed that it be referred to as the "tuber flea beetle." Recently this common name was approved by the American Association of Economic Entomologists (61).

According to Gentner (27), the tuber flea beetle is known to occur in Washington, Oregon, Colorado and western Nebraska. Although not listed from Wyoming, it is known to the writer that this insect occurs in the irrigated section near Torrington. Fulton and Glendenning (26) recently recorded its presence in the Canadian province of British Columbia. It has not been found in Idaho, Montana or South Dakota, and, although tuber injury has been reported from Utah (53), specimens of the black species of *Epitrix* from that state were not available to Gentner for examination. None of the *Epitrix* species found in California, Arizona and New Mexico is considered as the tuber flea beetle (27).

Apparently the tuber flea beetle reaches its eastern, and the potato flea beetle, *E. cucumeris*, its western limits in Nebraska.[1] In 1944, Gentner (27, p. 141) stated, "All of the specimens which I have examined from eastern Nebraska were *cucumeris*, and also two specimens from western Nebraska." Of 33 specimens later submitted from central Nebraska near Shelton and Gibbon, one was designated *E. tuberis*, the remainder *E. cucumeris*.[2] In 1945 and 1946 flea beetles were collected from potatoes at various localities across the state. These were identified by the writer, largely through the aid of characters given in Gentner's key. The resulting determinations are summarized, along with the identifications referred to above, in Table 1. To illustrate further the general distribution of the species within the state a map (Fig. 1) based on the same data is presented.

In addition to the two forms already discussed, a third black species, *Epitrix fuscula* Crotch, the eggplant flea beetle, often is found abundantly on potatoes at Lincoln and other eastern localities (Table 1). This species also apparently reaches its western limits in Nebraska. An examination of the black *Epitrix* specimens in the Iowa State College collection at Ames revealed the presence of only *E. cucumeris* and *E. fuscula*.

---

[1]Mills, *et al.* (60) reported that one specimen of *E. cucumeris* had been taken in Montana. The specimen was identified as that species by Gentner.

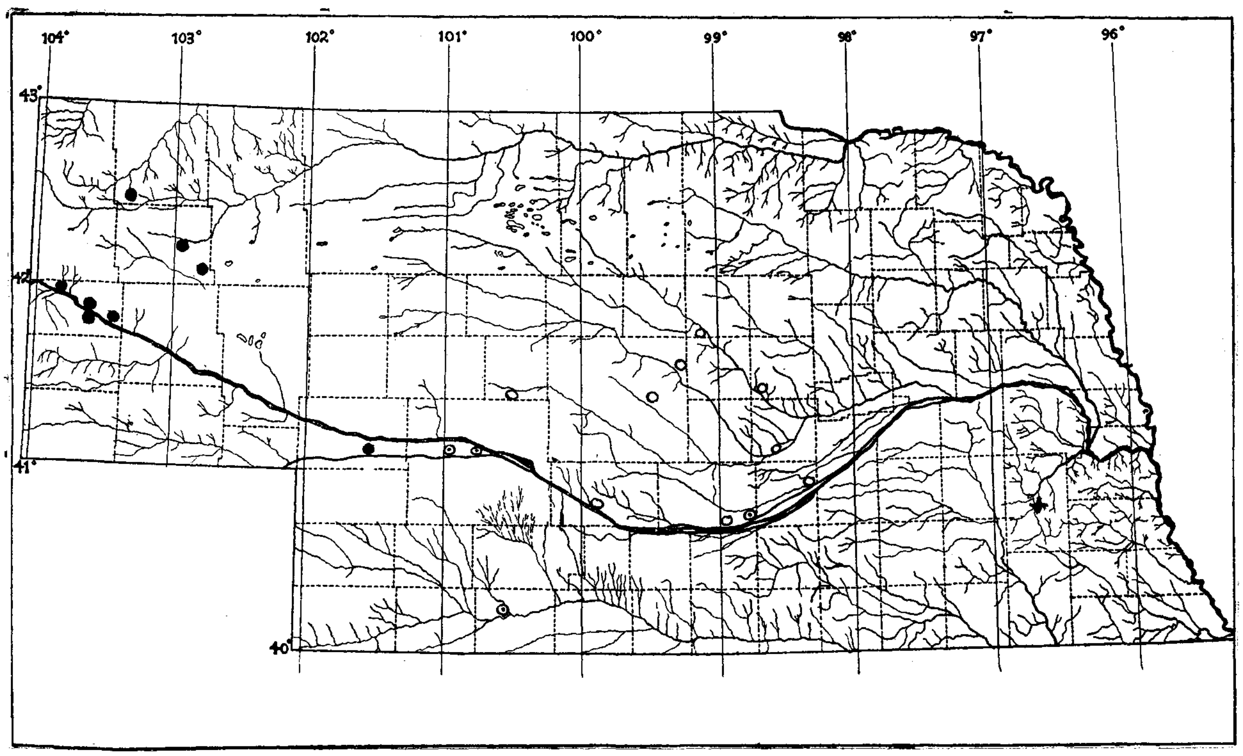
[2]Private letter from L. G. Gentner, Southern Oregon Branch Experiment Station, Route 4, Medford, Oregon, November 23, 1945.

Table 1. Distribution of the three black species of the genus *Epitrix* found on potatoes in Nebraska.

Locality[a]	Date of collection	Number of each species		
		E. tuberis	*E. cucumeris*	*E. fuscula*
Mitchell	June 24, 1943	251[b]	0	0
Mitchell	June 28, 1943	3[b]	0	0
Scottsbluff	June 28, 1943	104[b]	0	0
Scottsbluff	Sept. 27, 1940	58[b]	0	0
Gering	June 29, 1943	8[b]	0	0
Minatare	Aug. 1, 1945	150	0	0
Belmont	Aug. 26, 1945	83	0	0
Berea	Aug. 28, 1943	77[b]	0	0
Alliance	Aug. 20, 1943	87	0	0
Ogallala	July 11, 1945	2	0	0
Hershey	Sept. 17, 1946	26	17	0
North Platte	July 8, 1946	1	45	0
North Platte	Aug. 27, 1946	12	46	0
McCook	June 19, 1946	2	13	0
Stapleton	June 18, 1946	0	27	0
Cozad	June 20, 1945	0	15	0
Broken Bow	June 18, 1946	0	16	0
Comstock	July 3, 1946	0	86	0
Burwell	June 17, 1946	0	11	0
Gibbon	June 17, 1941	0	27[b]	0
Shelton	June 17, 1941	1[b]	5[b]	0
Scotia	June 17, 1946	0	42	0
Dannebrog	June 17, 1946	0	14	0
Grand Island	June 12, 1946	0	6	0
Grand Island	June 17, 1946	0	10	0
Grand Island	July 3, 1946	0	24	0
Lincoln	May 30, 1946	0	27	1
Lincoln	June 12, 1946	0	25	32

[a]Arranged from west to east across the state.

[b]Determined by L. G. Gentner.



●- *Epitrix tuberis*
⊙- *Epitrix tuberis* and *E. cucumeris*
○- *Epitrix cucumeris*
+- *Epitrix cucumeris* and *E. fuscula*

Fig. 1. Distribution of the three black flea beetles found on potatoes in Nebraska. (Based on data in Table 1).

Review of Literature

Since Harris (34) in 1835 first listed _Haltica cucumeris_ in his catalogue of Massachusetts insects and later (35, 36 and 37) called attention to its destructive nature, many papers have been published concerning the flea beetles found on potatoes. No attempt will be made to discuss this extensive literature in full; consideration will be given only to those articles directly applicable to the development of the present thesis.

Formerly it was believed that the larvae of potato flea beetles were foliage feeders. For instance, in 1869 Riley (65, p. 101) stated that "the larva feeds internally upon the substance of the leaf . . . ." As late as 1895, Harvey (38, p. 110) reported, "The larvae are said to live on the leaves attacked." Obviously these statements were based on inferences and not on direct observations. Apparently the first record of larvae feeding on roots and tubers of the potato was published in 1896 by Stewart (70, p. 311). He noticed in New York that "The wound made by the boring of the grub results in the formation of a 'sliver,' but a 'pimple' may or may not be produced . . . ." No mention was made of the type of injury known as "worm track." Since then various workers in the eastern states and Canada occasionally have observed "pimples" and "slivers," but apparently "tracks" seldom have been noticed (1, 3, 23, 31, 46, 74, 75 and 81).

Contrary to most eastern reports is that of Rawlins (62, p. 650), who states that in western New York "Large numbers of larvae of the potato flea beetle were found tunneling in growing tubers. Surface feeding, just below the epidermis resulted in long, narrow serpentine channels formed by the rupturing of the epidermis." He concluded that these injuries were not serious. However, in an agricultural extension bulletin from New York, Barrus and Leiby (7, p. 11) asserted that these tunnels beneath the skin and in the flesh resulted in lowering the grade of the potatoes. In fact, they stated, "Reductions in grade valued at $100 an acre have been reported by a few growers in seasons when flea beetles were abundant."

In general, however, it is obvious from the literature that serious tuber injury is of minor importance in the states east of Nebraska. Of prime consideration in the East are reductions in yields which frequently result following the feeding of large numbers of adults on the foliage. Although adult beetles also feed on the leaves in the western states, such injury generally is considered secondary to the lowered tuber quality resulting from blemishes produced by the larvae (15, 19, 24, 27, 33, 42, 43, 48, 54, 64, 76 and 78).

These differences in feeding habits have led entomologists to suspect that at least two species were involved - an eastern and a western form. Accordingly, Gentner (27) undertook a taxonomic study, discovered certain morphological differences and described the western form as new under the name _Epitrix tuberis_. Along with the description, Gentner discussed some of the literature and listed 91 references to flea beetles of which about 71 were considered as dealing with the species now known as _E. tuberis_.

In his discussion of the literature, Gentner (27, p. 141) declared that ". . . in no instance have 'worm tracks' been mentioned with reference to the eastern species. The latter type of injury seems to be characteristic of _tuberis_ only." He made no mention of the two articles already cited (7 and 62) in which "tracks" were reported on potatoes grown in New

York. Furthermore, tuberis was not reported from New Mexico; the specimens of black Epitrix which were collected there Gentner considered as being different and requiring further study. Yet two papers from that state indicate that tuberis is present. In 1900 Cockerell (15, p. 16), discussing flea beetles in New Mexico, stated "This pest not only injures the potato plant as a whole, but the larvae nibble the potatoes rendering them comparatively worthless." Eyer and Enzie (24, p. 29-30), also of New Mexico, very definitely referred to the "worm track" type of injury and reported that "During years when flea beetles have been abundant, certain potato-growing areas in the northern parts of the State have been unable to produce crops of marketable quality." These reports of "worm tracks" in areas now considered outside the range of E. tuberis indicate that this species either is present and/or that other species occasionally may produse similar tuber defects.

Life history studies of flea beetles on potatoes have been made in Maine (47 and 48), Iowa (75), Kentucky (46), Virginia (1 and 2), Ohio (31), Connecticut (10 and 74), Colorado (17, 18, 19 and 43), Washington (33, 51, 54 and 78) and Nebraska (40 and 72). In the first six states listed, E. cucumeris and/or E. fuscula were the species involved, whereas in Colorado and Nebraska the form studied was that now known as E. tuberis, and in Washington investigators were dealing with E. tuberis and/or E. subcrinita.

Early attempts to control flea beetles on potatoes generally were ineffective. Harris (37) suggested the use of a lime solution. Fitch (25) recommended dusting the plants with such materials as road dust, ashes, sulfur and lime as repellents. Other materials advocated included hellebore powder, or Paris green mixed with flour or plaster (38), London purple, decoction of tobacco, kerosene emulsion, wood ashes and tobacco powder (56).

The first distinct advance in control came in 1894 with the discovery by Jones (52), in Vermont, that Bordeaux mixture was repellent to potato flea beetles. Since then this material has remained a standard control measure in the eastern states, serving as both a fungicide and repellent. Frequently arsenicals, pyrethrum or rotenone materials have been added to Bordeaux mixture sprays (1, 12, 31, 74 and 75). The relative effectiveness of the various combinations has been the subject of much research in recent years and results obtained often have been conflicting (63).

In the western states the earliest recommended insecticides were much the same as those used in the East. Cockerell (15), Johnson (50) and Yothers (82) suggested sprays of Bordeaux mixture plus either Paris green or lead arsenate. Early in the 1910-1920 decade, experiments were undertaken in various parts of the United States with zinc arsenite; in some cases this was tried against potato insects (12 and 16). In 1917, Swenk and Wilcox (73) reported that tests in Nebraska showed zinc arsenite spray to be effective and recommended that this be used by the larger commercial growers for combatting the Colorado potato beetle and potato flea beetles. Following some experimental work in Colorado, calcium arsenate spray was advocated in 1928 by Hoerner and Gillette (43). Daniels (17) continued the Colorado investigations and, in 1933, suggested the use of a calcium arsenate-hydrated lime dust or a zinc arsenite spray. Although Daniels obtained effective results with dusts in 1933, later studies and experience led him to favor the use of sprays (18 and 19).

Shortly before 1930, Oregon and Washington investigators were testing dusts for controlling flea beetles. Webster and Baker (77), in Washington, obtained best results with a dust of hydrated lime, finely ground sulfur and nicotine sulfate (the mixture containing 2 per cent actual nicotine). They also tested various combinations of lead arsenate, calcium arsenate, sodium fluosilicate and sodium fluoride, each mixed with lime and sulfur, and with lime alone. Although some protection of the foliage was obtained with all these dusts, tuber injury was not controlled (4, 5 and 77). The recommended control measure advised by Baker (5) was Bordeaux mixture applied as soon as the leaves began to form. As a result of further work, the first recommendation of Webster, _et al_. (78), in 1932, was the use of either a barium fluosilicate (Dutox)-hydrated lime dust or a liquid spray containing this fluorine compound. A year later, Hanson (33), also of Washington, found that dusts of calcium arsenate and lime and barium fluosilicate and diatomaceous silica were the most effective insecticides for flea beetles. The best spray was a combination of calcium arsenate and Bordeaux mixture.

In 1938, Besse and Burtner (8) reported excellent kills in Oregon with a dust of rotenone mixed with either cryolite or calcium arsenate and using talc or diatomaceous earth as a carrier. However, this mixture was regarded as impractical to use because of the high cost of the materials.

At the time the present flea beetle project was started in Nebraska (1940) zinc arsenite sprays were being given first place in recommendations to potato growers in Colorado (18), New Mexico (24) and Nebraska (72). In the Pacific Northwest, however, various dusts apparently were favored (8, 33 and 79). About 135,000 pounds of a rotenone-cryolite dust were used by potato growers in Kittitas County, Washington, in 1940 (79).

Recent work with DDT has shown that this material gives excellent control of most potato insects, including the flea beetles (11, 30, 32, 39, 64 and 68). Because of the marked effectiveness of this insecticide it is likely that important changes soon will be made in control recommendations throughout potato growing areas of the United States. Not only is it likely that changes will be made in formulations, but methods of application also probably will be greatly modified. The aerosol method of applying DDT has given effective results against the potato flea beetle in the field in Maine and New Jersey (28 and 69). The increased use of airplanes for applying sprays and fogs as well as dusts to potatoes is already a present trend.

A few attempts to control flea beetles with soil fumigants, repellents or seed treatments have been made. Hanson (33) placed paradichlorobenzene and crude naphthalene flakes in furrows about 5 inches from the potato plants. In this way the amount of tuber injury was reduced 35 and 39 per cent, respectively. Besse and Burtner (8) reported on tests conducted in Oregon in 1937 with seed treated with rotenone-bearing compounds. Potatoes grown from such seed showed 50 per cent less flea beetle injury than potatoes harvested from untreated plots. MacMillan and Schaal (57), studying the relationship of scab, *Actinomyces scabies*, to flea beetle injury, found that tubers grown from treated seed were attacked by larvae just as readily as the untreated, but that the surface did not become rough or "pimply."

In addition to sprays, dusts, soil and seed treatments, numerous other means of controlling flea beetles have been attempted with varying degrees of success. Mechanical catchers, supplied with tanglefoot screens or cyanide and mounted on wheels or unmounted, have been devised and used for small plots of potatoes (43, 59, 71 and 80). Clean culture, destruction of weeds, crop rotation, proper drainage, adjustments of planting and harvest dates, and the use of resistant varieties all have been advised or tested (1, 17, 24, 33, 43, 45, 54, 67, 72 and 78). In 1899, Chittenden (14) advocated the use of jimson weed as a trap crop.

An interesting early control measure was that suggested by Johnson (49), who was perhaps the first fully to appreciate the seriousness of tuber injury. He recommended, in a 1904 Colorado press bulletin, that potatoes be dug as early as possible and that the tubers be left ". . . exposed to the air and sunshine for at least a few hours, preferably a day, before picking from the ground." He also stated that "This treatment will largely prevent further depredations by the insect, but in case the damage should be continued in the stored tubers, some method of fumigation must be resorted to."

BIOLOGY

Life Stages and Habits

Adult

Description. Gentner (27, p. 137-138) described the adult of *Epitrix tuberis* as follows:

> Elongate ovate, piceous, moderately shining. Antennae rufotestaceous, outer five joints darker. Head smooth, with a few punctures near each eye. Eyes not prominent, their combined width when viewed from the front less than the interocular distance. Pronotum less than one-half wider than long, narrowed somewhat anteriorly, anterior angles obliquely truncate, sides moderately arcuate, disc convex, especially anteriorly, punctures moderately coarse, closely spaced, usually separated by less than their diameters, somewhat finer and sparser anteriorly, transverse ante-basal impression sinuate, deep, with many fairly coarse punctures, longitudinal impressions at either end well marked. Elytra scarcely wider at base than pronotum, lateral margins somewhat subparallel, humeri not prominent, umbones moderately distinct, disc feebly convex, striae feebly impressed, punctures large, closely placed, finer toward apex, intervals very narrow. Legs rufotestaceous, anterior and middle femora fuscous, posterior femora piceous. Males: length 1.60-1.96 mm., width 0.84-1.08 mm.; females: length 1.80-2.04 mm., width 0.96-1.12 mm.

According to Gentner (27, p. 139), *tuberis* "may be distinguished from *cucumeris* by its densely punctate pronotum, less prominent, more widely separated eyes, subparallel elytral margins, and somewhat subdepressed disc of the elytra." A drawing of the adult is shown in Plate 1, Fig. 3.

The sexes may be separated on the basis of certain external characters. In the males the first tarsal joint of the anterior legs is enlarged and widened, whereas in the female this joint is normal or not widened. The last ventral segment of the male is subtruncate at the middle of the posterior margin, and with a reddish colored area on the disc extending from the posterior almost to the anterior margin. This area is slightly concave in some individuals but in others it appears as a distinct oval concavity. The apical ventral segment of the female is convex, uniformly black and with the posterior margin tapering normally. (See Plate 1, Figs. 4 and 5.)

<u>Hibernation and spring emergence</u>. In the fall of 1940 four cages, and in 1941 five cages (2' x 2' x 4' in size and covered with cheesecloth) were placed over typical field environments and adult beetles introduced as indicated in Table 2. Unless food was available in the form of green plant growth within the cages, either green potato foliage or cut tubers were supplied as long as the beetles remained active. Escape of the beetles through lateral movement in the soil was precluded by a 9-inch metal strip which extended downward from the sides of the cages. The cheesecloth cover was removed after the beetles had gone into hibernation in order to expose them to more natural winter conditions. Prior to insect activity in the spring, a new cover was installed. When emergence began in the spring all active beetles were counted and removed at regular intervals.

Emergence of the overwintered adults from the soil began about May 20 and continued until early in July, thus extending over a period of approximately 45 days. In both seasons the maximum daily emergences occurred during the interval from June 6 to 17 (Table 3). Of the 2,400 adults originally confined in the four 1940-41 cages, 449 or 18.7 per cent survived and emerged. In 1942, 522 or 17.4 per cent of the 3,000 caged beetles survived. The percentage survival under the various environmental conditions is shown in Table 2.

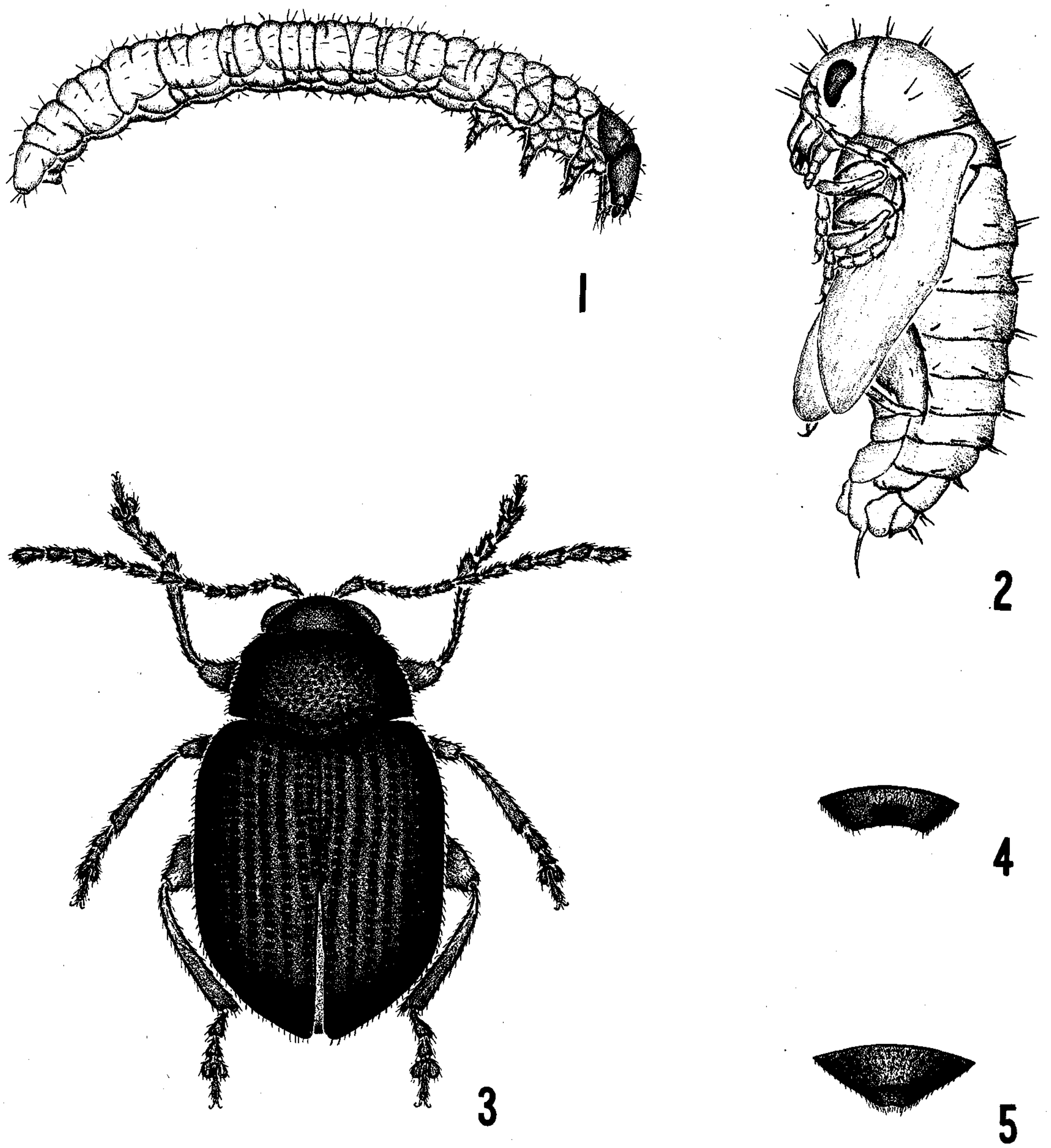


Plate 1. The tuber flea beetle, Epitrix tuberis Gentner. (1) Larva, (2) pupa, (3) adult, (4) apical sternite of male, and (5) apical sternite of female. All greatly enlarged and drawn to scale.

Table 2. Winter survival of Epitrix tuberis adults in outdoor cages at Scottsbluff, Nebraska.[a]

Ground cover	Per cent survival 1940-41	Per cent survival 1941-42
Potato soil - covered 3-4 inches with potato vines	34.5	23.7
Potato soil - bare	16.2	10.8
Irrigation ditch bank with grass and ground cherry	15.8	38.3
Irrigation ditch bank with grass and kochia	----	12.5
Alfalfa stubble	8.3	1.7
Average survival	18.7	17.4

[a]A total of 600 beetles placed in each cage September 20-28, 1940 and on September 16, 1941.

Table 3. Emergence of Epitrix tuberis from soil in hibernation cages and their spring appearance in alfalfa fields and along irrigation ditches at Scottsbluff, Nebraska.

Dates	1941 Average number beetles per 300 sweeps, alfalfa and ditch banks	1941 Number beetles taken from 4 cages	1942 Number beetles taken from 5 cages
May 13-18	30	0	0
May 19-24	7	3	8
May 25-30	60	14	0
May 31-June 5	75	92	77
June 6-11	-	131	209
June 12-17	185	144	168
June 18-23	85	41	39
June 24-29	27	14	21
June 30-July 6	2	4	-

Field collections, made with an insect net in an alfalfa field and along an irrigation ditch near Scottsbluff, corresponded closely with data obtained in the cage studies (Table 3). In 1941 the overwintered beetles appeared slightly earlier in the field, the earliest date being May 16 as compared to May 21 for the hibernation cages, but peak abundance of overwintered adults occurred at approximately the same time. The duration of the emergence period in the field likewise approximated that of the caged adults.

Feeding habits and host plants. Adult flea beetles produce a characteristic type of foliage injury. Although they are found on both the upper and lower surfaces of the leaves, most of the feeding is done on the lower side where they eat holes through the tissues to the upper epidermis. The remaining tissue dies and falls out, leaving small, round, shot-like holes (Fig. 2).

In western Nebraska the most important early spring host is the potato, including plants growing on cull piles along with volunteer plants in the field and the early-planted crop. Occasionally tomato plants may be damaged, particularly in the early part of the growing season. A number of other plants are fed upon to some extent at various times during the season (Table 4). Whenever potatoes are available, feeding is confined largely to that plant. Migrations of adults from early potatoes into nearby bean plantings frequently occur and considerable feeding has been observed in some instances. However, injury to crops other than potatoes is negligible.

At the time of harvest in late summer and early fall many adult beetles migrate from potato fields and again may be found feeding on a number of different plants. These hosts are principally the same as those of the

Table 4. List of plants found serving as adult hosts for *Epitrix tuberis* in western Nebraska.

Name	Spring hosts	Fall hosts
Alfalfa	X	X
Tomato	X	X
Pigweed (*Amaranthus retroflexus*)	X	X
Kochia (*Kochia scoparia*)	X	X
Turnip	X	
Lettuce	X	
Potato - volunteer and planted	X	X
Buffalo bur (*Solanum rostratum*)	X	X
Wild tomato (*Solanum triflorum*)	X	
Black nightshade (*Solanum nigrum*)	X	X
Field bean (*Phaseolus vulgaris*)	X	X
Corn	X	
Sweet clover	X	X
Ground cherry (*Physalis* spp.)	X	X
Sunflower (*Helianthus* spp.)	X	X
Giant ragweed (*Ambrosia* sp.)	X	X
Petunia	X	
Zinnia	X	
Hollyhock	X	
Sugar beet	X	X
Lamb's-quarters (*Chenopodium album*)		X
Cocklebur (*Xanthium commune*)		X
Eggplant		X
Bindweed	X	
Marsh elder (*Iva xanthifolia*)	X	X
Jerusalem artichoke (*Helianthus tuberosus*)		X
Round leaf mallow (*Malva rotundifolia*)		X
Green foxtail grass (*Setaria viridis*)		X
Cull potato tubers		X

early spring. Often the insects can be collected in large numbers on alfalfa late in the fall, probably because these plants remain green later in the season than most others in this area. Following harvest the beetles often feed extensively on cull tubers left in the fields, cracked or damaged tubers being especially attractive (Table 5).

Table 5. Number of adult flea beetles found feeding on or in broken tubers in harvested potato fields - Fall 1941.

Location of field	Date tubers collected	Number broken tubers examined	Number *E. tuberis* Total	Range	Average per tuber
Gering	Oct. 9	10	102	2-22	10.2
Gering	Oct. 9	10	619	8-203	61.9
Mitchell	Oct. 10	10	168	1-54	16.8
Scottsbluff	Oct. 11	10	398	2-147	39.8
Scottsbluff	Oct. 13	10	201	0-65	20.1
Total and average		50	1,488		29.8

__Copulation__. Tuber flea beetles often were observed mating in the spring and summer, and to a lesser extent in the fall. Pairing seems to take place any time of the day and is most conspicuous in the field during late June and early July, then again the latter half of August. Pairs confined to oviposition cages in the laboratory have been observed to mate three times.

__Oviposition__. Four pairs of overwintered beetles were placed in individual cages at the time of their mating in the spring of 1941. Detailed records were kept on the preoviposition and oviposition periods and the number of eggs deposited by each female. The preoviposition period ranged from 5 to 6 days; the oviposition period from 35 to 57 days, averaging 44.7 days; and the number of eggs per female from 161 to 215, averaging 187.2. Usually the eggs were deposited in batches of from 12 to 15, with intervals of from 1 to 2 days elapsing between successive depositions. Eggs were laid on consecutive days by individual females in only 15 per cent of the instances observed, whereas in 54 per cent of the cases an interval of from 2 to 3 days occurred.

In 1941 eggs were secured in the laboratory from a series of beetles that had oviposited during the previous season. On October 30, 1940, 33 of these beetles (reared and emerging as adults in the laboratory from July 1 to August 2) were placed in a typewriter ribbon box containing moist soil and buried 9 inches below the surface. Six of these survived the winter and were placed in oviposition cages in the laboratory May 25, 1941. Subsequently 23 eggs were deposited, indicating that some females may oviposit in two successive seasons.

Length of adult life. The length of adult life varies considerably. Three per cent of the overwintered beetles collected from May 20 to June 9, 1940 and confined in laboratory cages were still alive on October 28. Thus, these beetles had lived from 140 to 160 days under laboratory conditions. No records are available for length of life in the field. The quality of food plants has a marked effect on longevity as is shown later in Tables 10 and 11.

Egg

Description. The egg is small, elliptical in shape, measuring about 0.5 by 0.2 mm., and hence is difficult to see with the unaided eye. It is pearly white in color, changing to gray and tan with age. When viewed with a microscope fine pits may be seen on the surface.

Location. The eggs are laid in the damp soil around the base of the plant at a depth of an inch or more. They require moist soil for proper development. In the insectary eggs failed to hatch when kept dry. Given sufficient moisture and an average temperature of from 68 to 73 degrees Fahrenheit, the average duration of the egg stage ranged from 5.5 to 6.2 days.

Larva

Description. The larva is a slender, threadlike grub with body segments rather uniform in size. When first hatched it is about 1.0 mm. in length and white in color. As it matures the head and thoracic shield become light brown, the rest of the body remaining white. A full-grown larva is between 4.2 and 5.0 mm. in length, and generally resembles larvae of other members of the family Chrysomelidae. (See Plate 1, Fig. 1.)

Feeding habits and host plants. Larval feeding is confined to the underground portions of the plant. The underground stems, roots, stolons and developing tubers are attacked. By tunnelling along the surface of small tubers the larvae produce the blemishes known as "worm track" (Figs. 2 and 3). Often they penetrate the tuber a quarter of an inch or more at right angles to the surface. This type of injury commonly is referred to as "slivers," or if raised areas are found on the surface, such injuries are called "pimples" (Fig. 4).

Members of the family Solanaceae are the most important larval food plants for the tuber flea beetle. In Nebraska, prairie ground cherry, *Physalis lanceolata*, black nightshade, *Solanum nigrum*, buffalo bur, *Solanum rostratum*, potato, tomato, and field beans, *Phaseolus vulgaris*, have been found to serve as hosts for the larvae.

Length of larval stage. Under insectary conditions the average duration of the larval period ranged from 17.7 to 22.8 days. Because the larva feeds within the plant tissues it is difficult to study its development. The number of molts or instars was not determined. When mature the larva leaves its food plant and, after forming a small earthen cell, pupates.

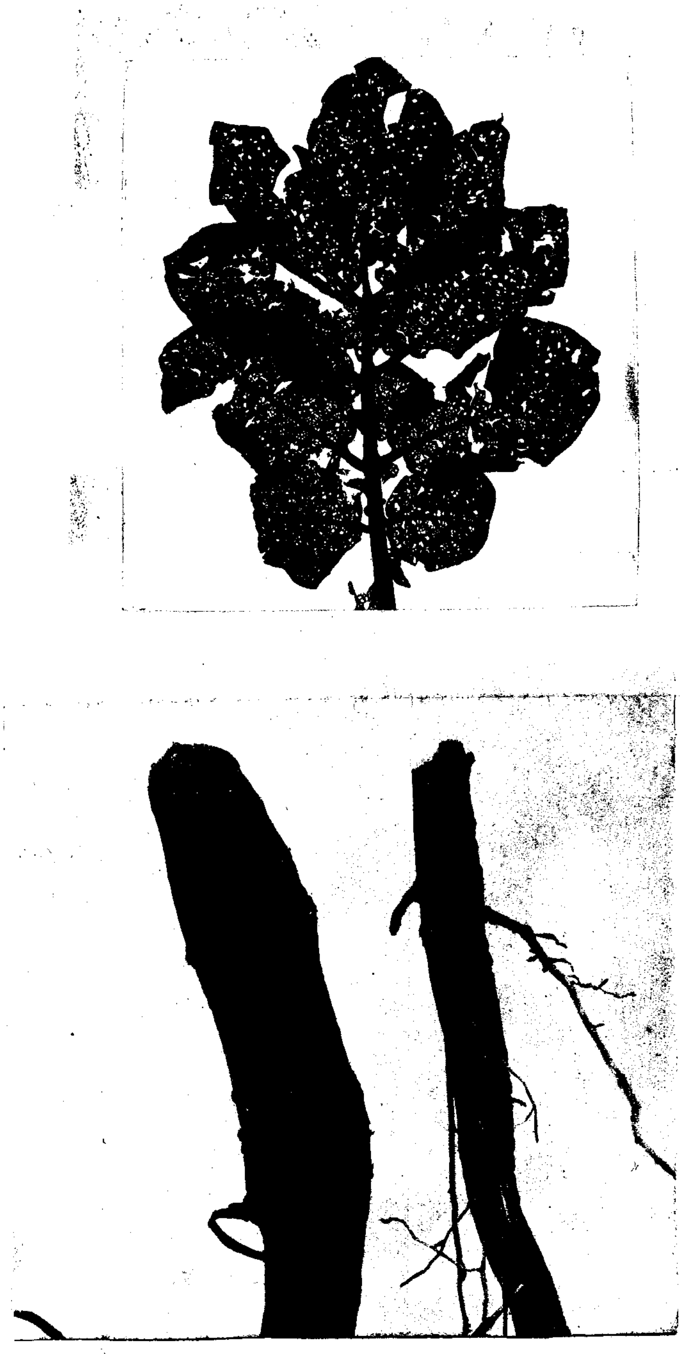


Fig. 2. Above: A potato leaf showing typical feeding punctures of the adult tuber flea beetle, *Epitrix tuberis*. Below: Evidence of larval tunnels in underground stems of potato (left) and black nightshade, *Solanum nigrum* (right).

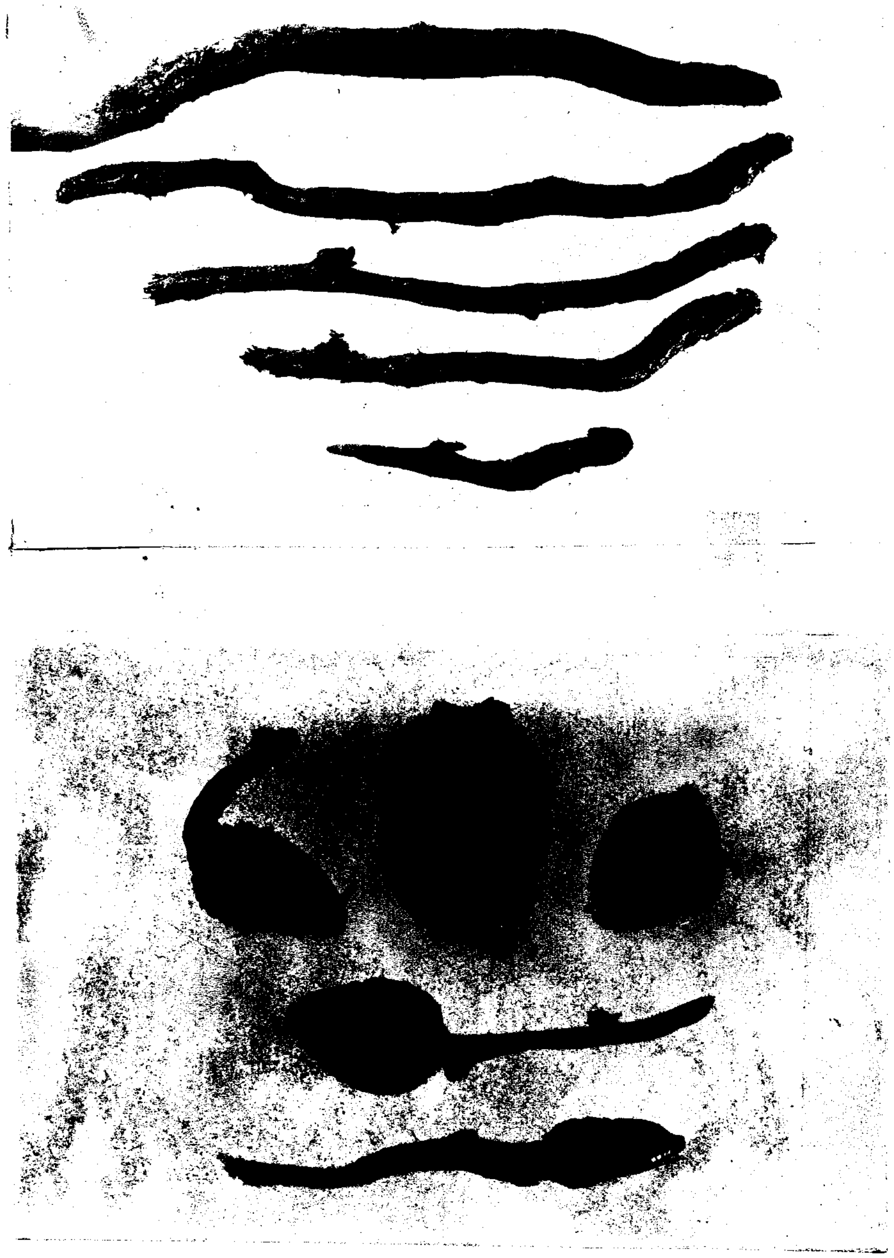


Fig. 3. Larval injury to underground parts of the potato plant. Above: Severely tunnelled potato stolons. Below: "Worm tracks" on small tubers.

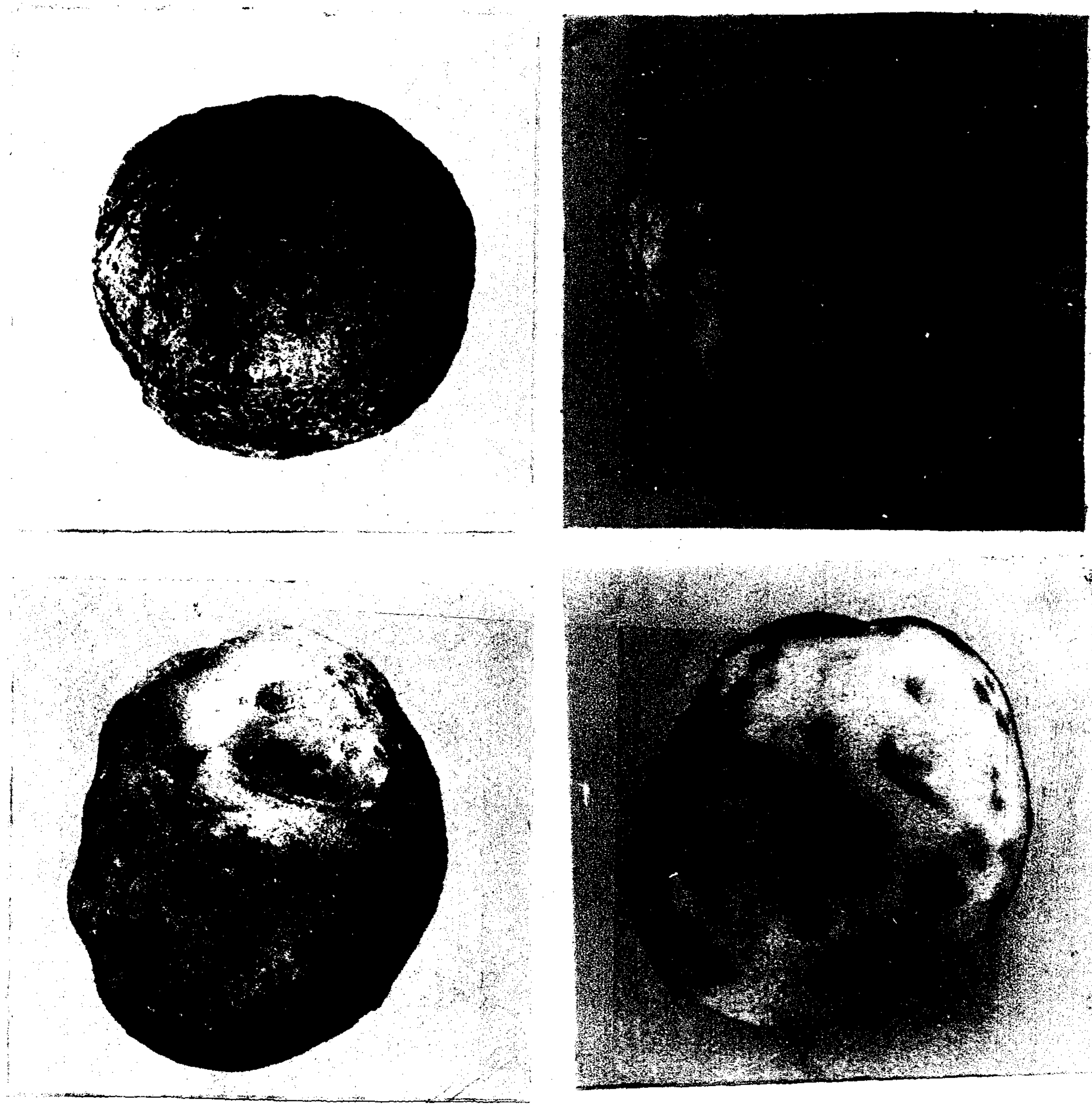


Fig. 4. Typical flea beetle damaged tubers. Above: Severe "worm track" before and after peeling. Below: "Pimples" before and after peeling. The black specks on the peeled tubers are the "slivers," the removal of which necessitates additional peeling and waste.

Pupa

Description. The pupa is white when first transformed and about the size of the adult. As the transformation continues it gradually darkens until the adult appears. The head is bent downward; the antennae which point caudad are partly hidden beneath the exposed first two pairs of legs. The third pair of legs lies partly concealed beneath the wings, and the apical segment of the abdomen is provided with a pair of curved spines. A lateral view of the pupa is shown in Plate 1, Fig. 2.

Location and duration of pupal stage. Most pupae are found in the soil beneath the potato plants at depths of from 1 to 3 inches below the surface. In the insectary the average length of the pupal stage varied from 5.8 to 11.2 days.

Life History Studies

Methods

The life history of the tuber flea beetle was studied in an insectary at the Scottsbluff Experiment Farm and the data thus obtained were supplemented by field records and observations. In general, the rearing technique used was similar to that employed by Johannsen (48), Hoerner and Gillette (43), Dominick (20) and Anderson and Walker (2). Instead of lantern globes, however, the cages were made of 30-mesh copper screen wire supported by a light metal frame (Fig. 5). For obtaining data on oviposition the cages were placed on dark blue blotting paper in contact with moist sand in flower pots. Moisture was supplied through capillary action by placing each pot in a shallow pan of water. Individual eggs were placed in salve boxes, about

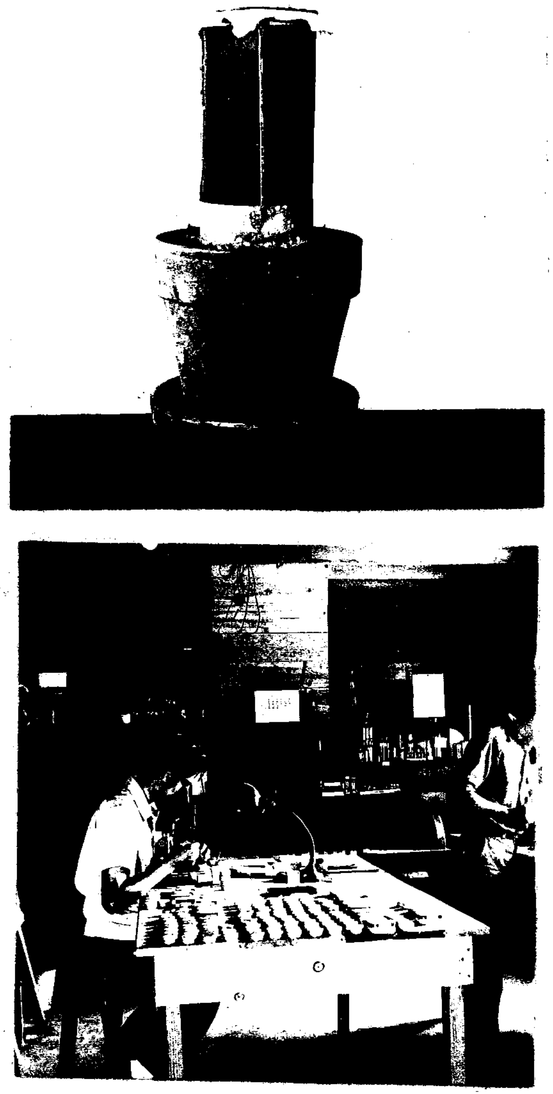


Fig. 5. Above: Type of oviposition cage used in life history and food plant studies. Below: Partial view of the Scotts Bluff Substation insectary, showing salve boxes used in study of egg, larval and pupal development.

45 mm. in diameter and 20 mm. in height, the bottoms of which contained sand covered with blotting paper. Moisture was added if needed, but more frequently it was difficult to prevent the accumulation of excess moisture.

As the eggs hatched, the larvae were transferred to small pieces of potato tuber and placed in salve boxes. Moisture was provided by lining the bottom of the container with blotting paper and then adding water as needed. As the larvae reached maturity, an environment favorable for pupation was obtained by partially filling the box with fine soil. Newly formed pupae were removed and placed on slightly moistened soil in another salve box for the duration of the pupal period.

First generation

In 1940 beetles began emerging from hibernation May 20, and from individuals caged between this date and May 24, two generations were reared during the year. The first eggs were deposited on May 27 and the first adult emerged on July 1. Egg deposition began 3 to 7 days following confinement and continued to August 14, or over a period of 80 days, with the peak coming June 18. These determinations are based on a total count of 15,910 eggs. The incubation period of the 5,865 eggs involved in the test ranged from 3 to 11 days, averaging 5.5 days. From eggs selected at random from the above series, records were obtained on 2,431 larvae, and the period of activity of these extended from June 3 to August 24. The range for individual larval development was from 13 to 29 days with an average of 18.45 days.

Pupation began June 23 and continued until August 24, or over a period of 62 days. On the basis of 287 individual records, the pupal stage was found to extend over a period of 4 to 10 days with an average of 5.8 days.

First generation adults appeared on July 1 and continued to emerge until August 30, a period of 2 months.

In 1941, 137 overwintered beetles were collected at the time of their emergence from hibernation between May 17 and June 30 and placed in cages. Egg deposition began on May 26 and the first adults emerged on July 5, 40 days later. For these beetles the oviposition period, which extended from May 26 to August 22, was 88 days, and the incubation period from 3 to 14 days, averaging 6.2 days. Of 1,529 eggs under observation, 1,220, or 79.79 per cent, hatched.

Larvae were present from June 6 until August 24. The average developmental period of the 191 larvae involved in this test was 17.7 days, with a range of from 14 to 23 days. The pupal stage ranged from 3 to 9 days, averaging 6.29 days. Although larvae continued to emerge until August 24, no pupations occurred after August 12. Of the 191 pupae under observation, 132, or 69.1 per cent, emerged as adults. First generation adults appeared on July 5, reached a peak July 22, and continued to emerge until August 25, a period of 51 days.

<u>Second generation</u>

As the first generation beetles in the 1940 tests emerged in the insectary, a total of 132, selected at intervals from July 1 to 17, were placed in oviposition cages. The first eggs of the second brood were deposited on July 13, and the first adult appeared on August 12, 30 days later. Oviposition extended from July 13 to October 3, or over a period of 82 days, and the peak occurred on August 11. The incubation period of the 7,838 eggs on which records were kept ranged from 3 to 20 days, averaging 5.9 days. Of the 3,743 eggs placed under observation, 3,252, or 86.88 per cent, hatched.

Larval activity extended from July 18 to November 3, and the average larval period was 22.76 days. Some individuals completed their development in as few as 15 days whereas others, near the close of the season, spent up to 43 days as larvae. Cold weather prevented complete development of all that hatched in late September and thereafter. The pupal stage ranged, on the basis of 299 individual records, from 5 to 22 days, averaging 11.16 days. Emergence of second generation adults began August 12, reached a peak September 15, and continued until early November, when cold weather prevented further activity.

A summary of all the rearing records included in this report is given in Table 6 and Fig. 6.

Table 6. The range and average duration of the various stages of *Epitrix tuberis* in the insectary at Scottsbluff, Nebraska.

Period	Generation	Year	Range, days	Average, days	Temperature[a]
Incubation	First	1940	3-11	5.5	72.7
		1941	3-14	6.2	69.4
	Second	1940	3-20	5.9	68.3
Larval	First	1940	13-29	18.45	73.1
		1941	14-23	17.7	70.8
	Second	1940	15-43	22.76	65.7
Pupal	First	1940	4-10	5.8	75.4
		1941	3-9	6.29	72.2
	Second	1940	5-22	11.16	61.6
Total developmental	First	1940	27-50		73.7
		1941	27-46		70.8
	Second	1940	30-85		65.2

[a]This represents the average mean daily temperature for the interval from the time the first individual appeared in a given stage until the last individual in the group had transformed to the succeeding stage. The same procedure was applied to all stages of both generations.

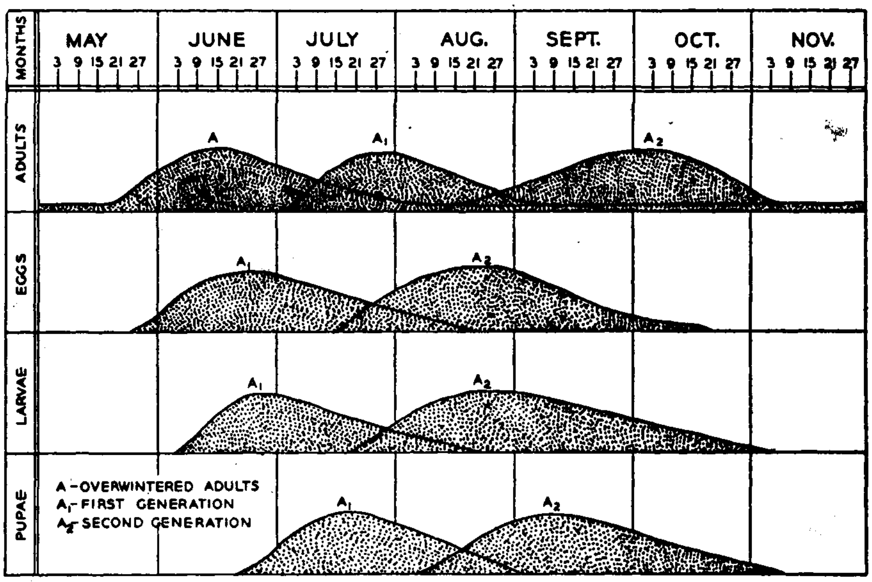


Fig. 6. Summary of the seasonal history of Epitrix tuberis based on records obtained at Scotts Bluff Substation in 1940 and 1941.

Third generation

Several of the second generation adults reared in the insectary during 1940 were placed in oviposition cages, but no eggs were laid. However, field observations have indicated that a partial third generation occurs during certain seasons. A record of the light-colored (newly emerged) adults collected with an insect net from a June 3 planting of potatoes suggested such was the case in 1943. This record is presented in Table 7.

Table 7. An indication of a partial third generation as shown by number of newly emerged adult tuber flea beetles in a June 3, 1943 planting of potatoes at Scottsbluff.

Date of collection	Average number of newly emerged beetles per 100 sweeps of net
July 13	1
July 20	53
July 25	44
July 31	7
Aug. 7	1
Aug. 18	9
Aug. 25	29
Sept. 1	8
Sept. 8	3
Sept. 19	1
Sept. 26	3
Oct. 4	8

An examination of the table reveals two definite "peaks," one on July 20 and the other on August 25, corresponding to the peaks of abundance for the first and second generations. It is the third increase, beginning about September 26 and continuing through October 4, or just prior to the time of harvest, that suggests the development of a third generation.

Natural Enemies

Flea beetles seem to be comparatively free of parasites and predators. During the course of these investigations no parasites were discovered. However, in the East braconids have been reported (12, 14 and 21) as enemies of the potato flea beetle and the tobacco flea beetle, *Epitrix hirtipennis*.

In Nebraska a large lacewing nymph once was observed feeding on an adult *E. tuberis* in the field. Under conditions prevailing in cloth-covered outdoor cages predation of adult flea beetles by *Collops* sp. (Family Malachiidae) and a *Nabis* sp. has been observed. Chamberlin and Tenhet (13) reported that a lygaeid, *Geocoris punctipes*, sometimes attacks adults of *E. hirtipennis*.

While searching through the soil around potato plants for flea beetle pupae in late September, a species of ground beetle, determined as *Harpalus funestus* Leconte,[1] frequently has been encountered. Flea beetle pupae placed on the ground in front of the carabids were quickly devoured. This indicates that certain species of carabids may be important predators of the immature stages of the tuber flea beetle.

Relationship to Potato Diseases

It has been shown that flea beetles are responsible for the dissemination of certain potato diseases. MacMillan and Schaal (57) demonstrated that the scab organism, *Actinomyces scabies* (Thaxter) Güssow, infects the tissues injured by the larvae of the tuber flea beetle. Under field con-

[1]Determined by Dr. B. E. Rees, Bureau of Entomology and Plant Quarantine, Washington, D. C.

ditions larvae were found to carry the scab organism both internally and externally. These men also proved experimentally that the larvae are capable of transferring the scab organism from infected soil and diseased potatoes to healthy potatoes. Scab-infected "worm tracks" are conspicuous and thus are more likely to decrease the market value of the potato than are the uninfected blemishes. Sometimes Rhizoctonia solani, a fungus, invades the larval blemishes, thus intensifying the damage. In western Nebraska this has been observed most often on potatoes from early plantings.

Goss (29), working in western Nebraska, secured transmission of potato spindle tuber and potato unmottled curly dwarf (both virus diseases) by means of adult flea beetles. According to Leach (55) this transmission is believed to be purely mechanical in nature.

Circumstantial evidence has been presented by Martin (58) showing that flea beetle feeding punctures in leaves serve as infection centers for the early blight organism, Alternaria solani Jones and Grout, on tomato. Since this fungus also is responsible for early blight of potatoes, it is not surprising to find that Barrus and Chupp (6) claim a similar relationship on that crop. The few casual observations made in western Nebraska to date have indicated no close relationship between flea beetle feeding punctures and early blight lesions.

Factors Influencing the Abundance of Flea Beetles

Factors found to be of most importance in influencing the abundance of tuber flea beetles in western Nebraska are weather conditions, especially rainfall, irrigation, host plants, date of planting the potato crop, and the presence or absence of cull dumps.

Rainfall

There is a significant relationship between flea beetle abundance, tuber injury and precipitation in western Nebraska. Moist years are most favorable for flea beetle development and subsequent tuber injury. Although the total annual rainfall is significant, the moisture received during the fall and following spring is of greater importance in areas such as Scotts Bluff County where irrigation is widely practiced. In non-irrigated sections (Box Butte, Banner and part of Kimball Counties) the July and August rainfall is of relatively greater significance, an abundance favoring the development of these insects.

Adequate precipitation during September and October permits the beetles to find more suitable hibernation quarters, and the spring rains during May and June are factors affecting the emergence of overwintered adults. A number of investigators (9, 22 and 44) working with other species of Coleoptera have shown that a sufficient amount of moisture coming at those times favors survival. In Nebraska, one or two good rains followed by a few warm days during the first half of June usually result in the rather sudden appearance of many overwintered flea beetles.

For the past several years bin inspectors of the Nebraska Certified Potato Growers Association at Alliance have been recording flea beetle damage on tubers in cellars at the time they made their fall inspections for potato diseases. These records were made available to the writer, and the information for Scotts Bluff, Kimball and Box Butte Counties is summarized along with pertinent precipitation data in Table 8. The relationship of rainfall to flea beetle damage, and hence abundance, is further shown graphically in Figs. 7, 8 and 9. A statistical analysis of the Scotts Bluff

Table 8. Relation of precipitation to per cent of bins showing flea beetle damage in Scotts Bluff, Kimball and Box Butte Counties during the ten-year period, 1936-1945, inclusive.[a]

Year	Scotts Bluff County			Kimball County			Box Butte County		
	Number bins inspected	Per cent bins showing flea beetle damage	Rainfall (deviation from normal)[b]	Number bins inspected	Per cent bins showing flea beetle damage	Rainfall (deviation from normal)[c]	Number bins inspected	Per cent bins showing flea beetle damage	Rainfall (deviation from normal)[d]
1936	105	2.9	-3.93	53	0.0	-3.08	30	0.0	-6.77
1937	190	6.3	-3.12	60	5.0	-2.60	59	0.0	-4.80
1938	277	31.4	-0.44	61	4.9	+1.47	62	0.0	-1.59
1939	327	32.1	-1.76	74	0.0	-0.48	53	0.0	-2.84
1940	459	19.6	-5.78	93	0.0	-4.21	62	0.0	-7.36
1941	352	82.7	+0.35	71	2.8	+2.01	86	4.7	+1.79
1942	195	70.7	+0.89	29	75.9	+3.16	79	30.4	+5.65
1943	255	69.8	-1.12	44	54.6	+1.58	82	57.3	-0.63
1944	351	41.9	-3.20	61	41.0	+3.26	112	16.1	+1.37
1945	277	31.0	-1.34	31	45.1	+3.48	62	48.8	+2.60
	Average	38.8			22.9			15.7	

[a]Inspection records through courtesy of Marx Koehnke, Certification Manager of the Nebraska Certified Potato Growers Association, Alliance, Nebraska.

[b]From official weather report Scottsbluff, Nebraska for previous September and October and current May and June.

[c]From official weather report Kimball, Nebraska for previous September and October and current May, June, July and August.

[d]From official weather report Alliance, Nebraska for previous September and October and current May, June, July and August.

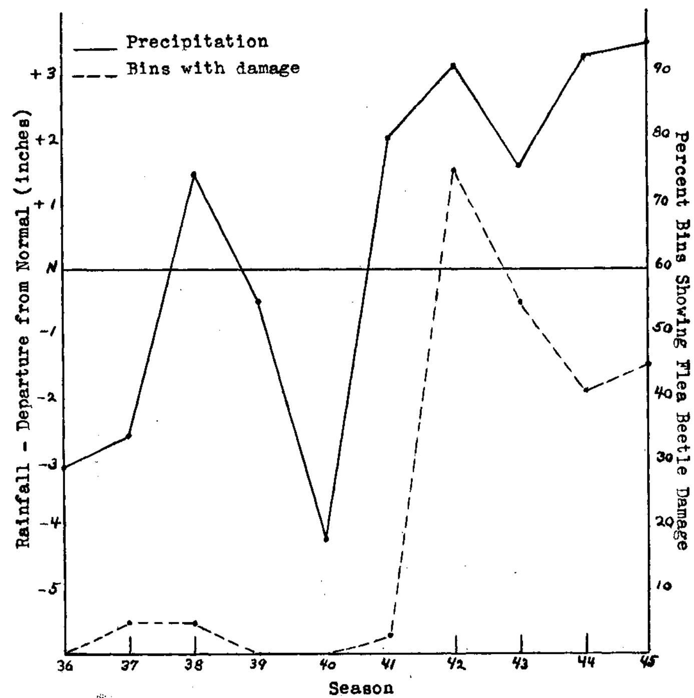


Fig. 7. Relation of precipitation (for previous September and October and current May, June, July and August) to per cent bins showing flea beetle damage in Kimball County (1936 to 1945, inclusive). Heavy line, precipitation; broken line, per cent bins showing damage.

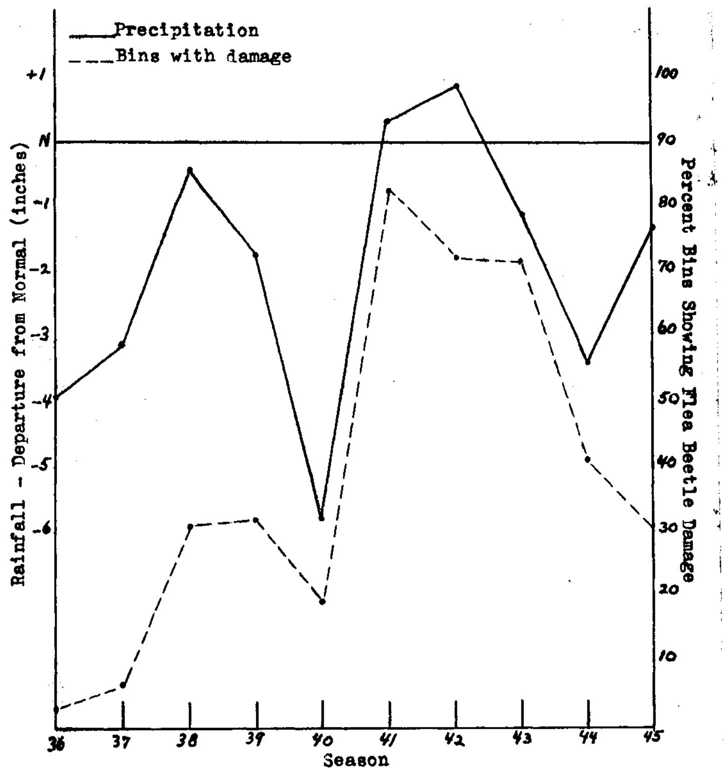


Fig. 8. Relation of precipitation (for previous September and October and current May and June) to per cent bins showing flea beetle damage in Scotts Bluff County (1936 to 1945, inclusive). Heavy line, precipitation; broken line, per cent bins showing damage.

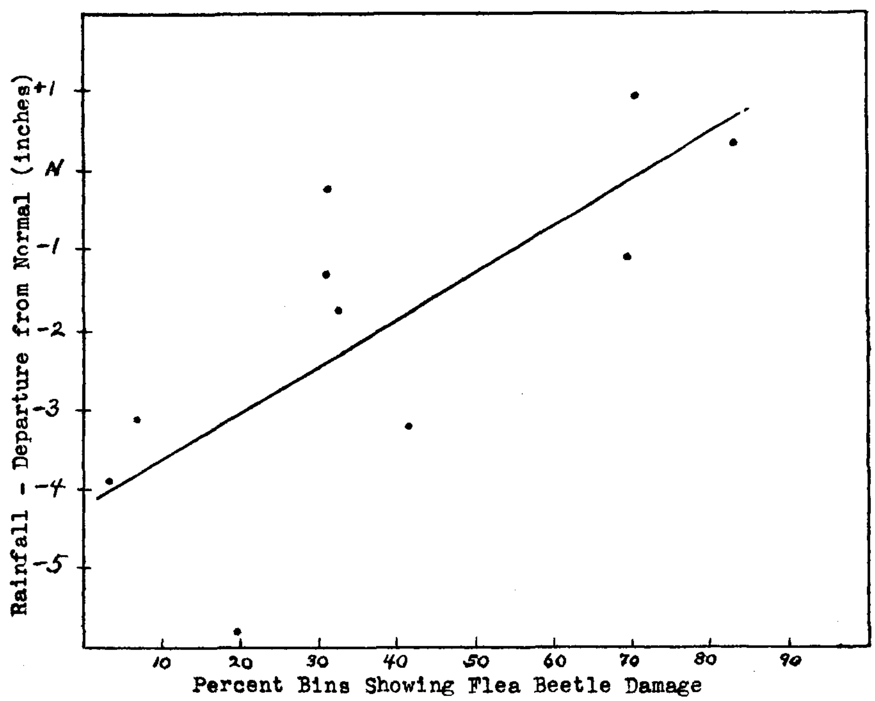


Fig. 9. Relation of precipitation (for previous September and October and current May and June) to per cent bins showing flea beetle damage in Scotts Bluff County. The heavy line represents the regression line and each dot the data for one year. The period covered is 10 years (1936 to 1945, inclusive).

and Kimball data disclosed significant correlation coefficients of 0.743 and 0.700, respectively. Although data for Box Butte County parallels that of the other two counties, the correlation coefficient of 0.582 is a little below the 0.632 value considered necessary for significance. Nevertheless it is evident that no damage was found during the five driest years (1936 to 1940, inclusive) and that following the increased precipitation of the next five seasons tuber injury was recorded.

<u>Irrigation</u>

Further information regarding the influence of moisture on the development of flea beetles was obtained in an irrigation experiment conducted during the 1946 growing season at the Scotts Bluff Substation. This test, designed primarily to study effects of different levels of moisture, spacing and fertility on the development and yield of a late planted field of potatoes, was undertaken by the University of Nebraska Departments of Agronomy and Horticulture in cooperation with the United States Department of Agriculture Bureau of Plant Industry, Division of Western Irrigation Agriculture. Since no attempt was made to control insects, the experiment provided an opportunity to observe the extent to which flea beetle damage was influenced by the treatments. The three moisture levels (1, 2, and 5 or 6 irrigations) were replicated 18 times in three-row plots 125 feet long. A 50-foot strip from the center row was harvested. Before the potatoes were picked up and sacked, a random sample of 20 tubers was taken uniformly along each row and examined later for larval blemishes. The results of this examination are listed in Table 9. The difference in number of blemishes between plots receiving varying amounts of moisture is striking. Thus, in this one field

Table 9. Relation of irrigation to flea beetle injury in a field experiment at the Scotts Bluff Substation, 1946.

Treatment	Average number flea beetle blemishes per 20-tuber sample
One irrigation	17.4
Two irrigations	52.4
Five or six irrigations	134.4
Difference required for significance at 19 to 1 odds	33.8

experiment were simulated conditions prevalent in dryland and irrigated areas and in wet and dry seasons. The differences in larval damage parallel what has been observed under these conditions. The results of this experiment support the bin data presented in Table 8 and Figs. 7, 8 and 9, and further illustrate that an adequate moisture requirement is necessary for the development of an abundance of flea beetles.

Planting date

The potato planting date has a marked influence on the number of flea beetles developing in any locality. Early planted potato fields attract overwintered beetles in large numbers soon after emergence and therefore provide excellent conditions for the building up of a large population of first generation beetles. Net collections taken throughout the growing season in fields planted on different dates show higher average populations in the earlier planted fields. These differences are shown graphically in

Fig. 10, which is based on collections taken from several fields over a four-year period (1940 to 1943, inclusive).

Host plants

The influence of host plants on the general abundance of the tuber flea beetle was studied in some detail. It had been noticed in 1940 and 1941 that except for early growing potato plants in the field or on cull dumps, the spring hosts were of minor importance in the build-up of the destructive first generation flea beetle populations. Consequently, the elimination of early potatoes was proposed as one means of controlling this pest. However, if all early potatoes should be eliminated, would the beetles find their other spring food plants suitable for sustenance and reproduction? Experiments designed to obtain data on this question were undertaken during 1943 and 1944 at the Scotts Bluff Substation.

Method of study. Fecundity and longevity of the tuber flea beetle were studied in an outdoor insectary, and data on larval development were obtained by caging plants in the field. Flea beetles used in the insectary experiments were of the overwintered generation. These were collected individually by means of an aspirator directly from the various food plants. Immediately following capture the insects were placed in 30-mesh screen wire oviposition cages with foliage from the plant species upon which they had been feeding. Fresh food was supplied daily. Twenty beetles were confined in each cage, but since no attempt was made to equalize the sexes the number of egg-laying females probably varied somewhat from cage to cage. Whatever effect any unequal sex ratios may have had on the experimental results, it is evident from the data obtained that the sampling method was

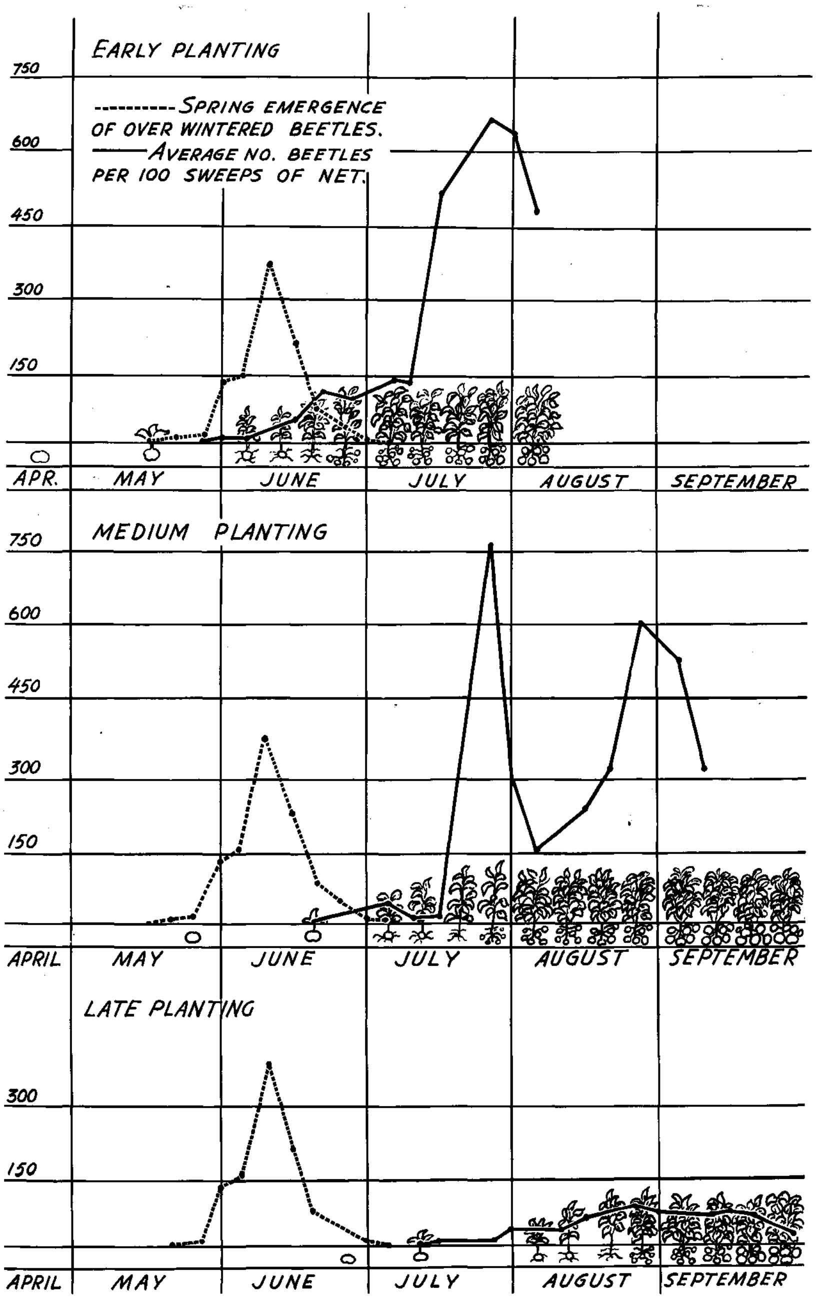


Fig. 10. Relationship of spring emergence to subsequent adult flea beetle populations in fields planted in late April, late May and late June, based on field records for 1940 to 1943, inclusive. Figures in left hand margin refer to the number of flea beetles collected per 100 sweeps of net.

sufficiently good to give marked differences in each test. Oviposition records were secured according to the method previously explained. The various experiments may be further described and differentiated as follows:

Oviposition and longevity experiment, 1943. Flea beetles were collected on June 26 from each of seven different species of plants. For 20 days thereafter the insects were maintained upon these original foods. At the end of that period, and for the next 20 days, potato foliage was substituted for field bean, _Phaseolus vulgaris_, marsh elder, _Iva xanthifolia_, kochia, _Kochia scoparia_, and buffalo bur, _Solanum rostratum_. No change was made in cages being supplied with wild tomato, _Solanum triflorum_, potato, _Solanum tuberosum_, or tomato, _Lycopersicum esculentum_. The insects there were kept on these original diets for the full 40-day experimental period (June 27 to August 5).[1]

Oviposition and longevity experiment, 1944. In 1944 (on June 3) adult flea beetles again were collected from seven different plant species. Hosts were the same as for 1943 except that prairie ground cherry, _Physalis lanceolata_, replaced wild tomato. Instead of one cage, duplicate cages were supplied with each of the original food hosts for a 20-day period. At the end of that time potato foliage was substituted in the six duplicate cages, beetles in the others being continued on the various original diets for the next 40 days or for the full 60-day experimental period (June 4 to August 2). Two check cages were set up to determine the length of life in the absence of food.

---

[1]Varieties of cultivated host plants used and referred to in this section are the Triumph potato, a tomato known locally as the Red Head, and the Great Northern field bean.

Alternating diet experiment. In 1944 a series of six cages was set up to study the effects produced by alternating food plants at 10-day intervals. The plant species used, and from which beetles were collected, were potato, marsh elder and buffalo bur. After 10 days foliage of buffalo bur and potato was substituted for marsh elder in the two cages originally started with that food. Similarly, marsh elder and potato replaced buffalo bur, and in the two potato cages marsh elder and buffalo bur were substituted for potato. At the end of the second 10-day period all cages again were supplied with the original foods. Diets thus were alternated every 10 days for a period of 60 days. The three cages in the 1944 oviposition and longevity experiment where beetles were confined continuously on diets of marsh elder, buffalo bur or potato served as checks in this test.

Larval development experiment. Field cages (2' x 2' x 4' in size and covered with cheesecloth) were used for obtaining evidence of larval development on the underground parts of various plant species. Early in July, 1943, these cages were placed over eight different species of plants growing naturally in the field and which consequently had been exposed to over-wintered flea beetles during the month of June. In 1944 this test was continued, cages being set over six different species of plants (Table 13). Since the foliage of all plants selected for caging showed considerable evidence of adult flea beetle feeding, it was assumed that if the species served as a larval host, evidence of such could be obtained by caging. These cages were examined at regular intervals from early July to mid-August and all emerging first generation beetles removed and counted.

Results. The results of the experiments have been summarized in the accompanying tables. An examination of Table 10, which is a combined

Table 10. Effect of different food plants and, after 20 days, of a change to potato on fecundity and mortality of tuber flea beetles.[a]

First 20-day period			Second 20-day period			Total number eggs laid during 40-day period	Per cent mortality end of 40 days	Total number eggs laid end of 60 days[b]	Per cent mortality end of 60 days[b]
Food plant	Number eggs laid	Per cent mortality of original population	Food plant	Number eggs laid	Per cent mortality of original population				
Kochia	14	15	Same	0	85	14	100	14	100
Kochia[c]	0	50	Potato	703	0	703	50	-	-
Kochia	0	20	Potato	679	20	679	40	1143	85
Marsh elder	124	0	Same	60	60	184	60	229	100
Marsh elder[c]	4	0	Potato	552	0	556	0	-	-
Marsh elder	78	0	Potato	893	0	971	0	1380	55
Ground cherry	45	5	Same	0	75	45	80	45	100
Ground cherry	2	15	Potato	748	0	750	15	1398	20
Bean	128	0	Same	39	70	167	70	188	100
Bean[c]	23	20	Potato	249	20	272	40	-	-
Bean	84	10	Potato	855	10	939	20	1562	45
Wild tomato[c]	567	0	Same	660	20	1227	20	-	-
Buffalo bur	98	0	Same	221	10	319	10	575	35
Buffalo bur[c]	64	10	Potato	342	15	406	25	-	-
Buffalo bur	68	15	Potato	510	0	578	15	767	55
Tomato	889	5	Same	579	20	1468	25	1556	65
Tomato[c]	797	0	Same	260	40	1057	40	-	-
Tomato	656	0	Potato	1394	0	2050	0	2865	85
Potato[c]	511	5	Same	127	10	638	15	-	-
Potato	307	0	Same	479	0	786	0	1011	35
Potato	866	0	Same	849	5	1715	5	2656	25
No food	15	100							
No food	2	100							

[a]Twenty flea beetles were confined in each of the 23 cages at the beginning of the experiments.

[b]Food in cages continued a third 20-day period was same as that fed during second 20-day period.

[c]Data from 1943 oviposition and longevity experiment. Remainder of table based on results of 1944 oviposition and longevity experiment.

summary of data obtained in the 1943 and 1944 oviposition and longevity experiments, shows great differences among various hosts with respect to their effects on oviposition and longevity of tuber flea beetles. Potato, tomato and wild tomato were the most suitable diets for maintenance and oviposition. Beetles confined on buffalo bur laid fewer eggs, but they subsisted satisfactorily on this plant. Fecundity and longevity were reduced by diets of bean, ground cherry, marsh elder and kochia. Increased egg production was obtained in all 10 cages where potato foliage was substituted as food following a 20-day feeding period on some other host. Substitution of potato foliage for less favorable food prolonged the life of the beetles. However, with the exception of kochia, a majority of the insects when fed single plant species were able to live on these foods for more than a month (Table 11). After 60 days there was complete mortality in cages where beetles were fed single diets of kochia, marsh elder, ground cherry or bean as compared to mortalities of 65, 35 and 30 per cent for beetles maintained on tomato, buffalo bur and potato, respectively.

The marked influence of food on egg deposition is more clearly emphasized by the results obtained in the alternating diet experiment, which have been summarized in Table 12. Alternating potato with either buffalo bur or marsh elder at 10-day intervals resulted in noticeable fluctuations in numbers of eggs laid. The response to the presence or absence of a potato diet occurred fairly promptly, usually two or three days following the change. Less fluctuation occurred when buffalo bur and marsh elder were interchanged (cages 1 and 2) and the total number of eggs laid by beetles fed in this manner was low. An examination of figures given in Table 12 indicates that buffalo bur may become more nutritious with age, or that beetles feeding on

Table 11. Survival period, total adult mortality and number of eggs deposited by tuber flea beetles confined on single diets or nothing.

Food[a]	Average survival following caging (days)	Period over which mortality occurred (days)	Per cent mortality of original population end of 20 days	40 days	60 days	Total number eggs laid
No food	9.0	(6-12)	100	100	100	15
No food	9.5	(4-17)	100	100	100	2
Kochia	26.8	(20-34)	15	85	100	14
Ground cherry	32.5	(20-48)	5	75	100	45
Bean	41.0	(22-60)	0	70	100	188
Marsh elder	41.2	(28-56)	0	60	100	229
Tomato	45.4[b]	(20-)	5	20	65	1556
Buffalo bur	48.0[b]	(34-)	0	10	35	575
Potato	54.0[b]	(42-)	0	0	35	1011
Potato	54.8[b]	(36-)	0	5	25	2656

[a]Twenty beetles placed in each cage.

[b]Some beetles still were alive at end of 60 days when experiment was terminated. Actually the average survival figure should be greater in these cages.

this host gradually but slowly obtain the food factors necessary for reproduction. Egg deposition tended to increase in cages 1, 2, 3 and 8 on buffalo bur diets. On marsh elder diets, egg production tended to drop but this probably was due, at least in part, to the lower subsistence value of this food plant.

Results of the larval development experiment, along with a complete summary of all oviposition data obtained from the other three experiments, are presented in Table 13. In addition to being the best food for egg production, potato also was most favorable for larval development since the greatest number of first generation adult beetles was collected in field cages set over potato plants. Although many beetles completed growth on tomato, it was much less satisfactory for larval development than was potato.

Table 12. Oviposition summary for tuber flea beetles fed single and alternating diets.

Cage No. 1[a]	Food plant: 1st, 3rd and 5th 10-day periods	Food plant: 2nd, 4th and 6th 10-day periods	Number eggs laid during following 10-day periods: 1st	2nd	3rd	4th	5th	6th	Number eggs laid while feeding on: Marsh elder	Buffalo bur	Potato	Total number eggs laid 60 days
1	Marsh elder	Buffalo bur	38	35	50	66	26	64	114	165	-	279
2	Buffalo bur	Marsh elder	35	14	41	37	187	18	69	263	-	332
4	Marsh elder	Potato	48	294	59	260	20	132	127	-	686	813
6	Potato	Marsh elder	504	266	858	93	812	14	373	-	2174	2547
5	Buffalo bur	Potato	44	291	47	319	63	139	-	154	749	903
3	Potato	Buffalo bur	219	25	168	77	318	171	-	273	705	978
7	Marsh elder	Marsh elder	61	63	43	17	45	0	229	-	-	229
8	Buffalo bur	Buffalo bur	85	13	74	147	114	142	-	575	-	575
9	Potato	Potato	331	535	373	476	598	343	-	-	2656	2656
					Total				912	1430	6970	
					Average per cage				182	286	1394	

[a]Twenty beetles placed in each cage at beginning of experiment.

Table 13. Number eggs laid by tuber flea beetles while on diets of various food plants in laboratory, and emergence of first generation adults in outdoor cages set over the same food plant species which had been naturally exposed during June to overwintered beetles, 1943 and 1944.

Food plant	Average number eggs laid in laboratory per cage per 10-day feeding period	Number outdoor cages	Average number first generation beetles collected per outdoor cage
Potato	333.0	2	445.0
Tomato	318.1	2	158.0
Wild tomato	306.8	2	0.0
Buffalo bur	71.0	4	7.2
Marsh elder	45.2	3	0.0
Bean	34.2	3	8.3
Ground cherry	7.8	2	2.5
Kochia	1.8	2	0.0
Black nightshade	-	2	37.5

Of the other plants tested, black nightshade, Solanum nigrum, and buffalo bur ranked third and fourth, followed by ground cherry and bean. However, relatively few beetles matured on these four species. Flea beetles developed in only one of the three cages placed over beans, and none in cages over marsh elder, kochia or wild tomato. The complete failure to obtain evidence of flea beetle development on wild tomato is interesting, since in the laboratory many eggs were deposited by females feeding on the foliage of this species.

Cull dumps

That the presence of volunteer growth on cull dumps (Fig. 11) is a factor in the abundance of flea beetles is evident from Table 14 showing the congregation of overwintered beetles in such places during the months of May and June.

Fig. 11. View of a typical cull dump in Scotts Bluff County. Note volunteer potato growth. (Picture through courtesy of Mr. R. L. Wallis, Associate Entomologist, United States Department of Agriculture Bureau of Entomology and Plant Quarantine, Scottsbluff, Nebraska.)

Table 14. Number overwintered tuber flea beetle adults collected per 100 sweeps of insect net on two cull dumps near Mitchell, Nebraska, 1943.

	May		June			
	20	25	2	10	16	23
Dump A	2	1	48	148	251	660
Dump B	0	2	12	16	259	738

Evidence that first generation beetles develop from eggs laid on cull potatoes was obtained in 1942. On July 1, a cage was placed over a small portion of a cull pile (20 inches square and about 7 inches deep), which had been exposed naturally to overwintered adults during the month of June. The cage was examined daily, from July 3 to 28, and all beetles present were counted and removed. A total of 722 beetles developed in and emerged from the small area enclosed.

CONTROL

Agronomic Control

Planting date

In western Nebraska most of the potato crop now is planted after June 10, but a few fields and garden patches are planted during the latter part of April and in May. Plantings made previous to about May 25 are considered "early" potatoes, those planted from May 25 to June 10 as "medium," and as "late" those made after June 10. Usually all potato fields have been planted by July 1.

The severity of tuber injury is influenced to a marked extent by date of planting, being much more acute in early fields. This relationship is shown in Tables 15 and 16. Even with five or six dust applications (Table 16) a very low yield of high quality tubers was obtained with the earlier plantings.

Although the low total yields generally recorded for early plantings are due largely to the seasonal weather (which is relatively unfavorable for tuber formation), some evidence was secured in 1943 showing that tuber flea beetle larvae also may be partly responsible. Sixteen potato plants were dug at weekly intervals from plots of potatoes planted on the following three dates: May 22, June 3 and June 24. The underground parts were taken to the laboratory where records were kept regarding stolon and tuber development, and of the presence of flea beetle larvae and their damage. The pertinent data is presented in Table 17. Although there were slightly more

Table 15. Comparison of flea beetle populations, foliage damage and tuber injury in untreated plots planted on three different dates at Scotts Bluff Substation, 1943.

Date planted	Average number flea beetles per 50 sweeps	Average number feeding punctures[a] per leaf	Total yield bushels per acre	U. S. No. 1 quality except for flea beetle injury bushels per acre	Loss due to flea beetles bushels per acre	U. S. No. 1 potatoes bushels per acre	Per cent loss from U. S. No. 1 grade because of flea beetle injury
May 22	215	119	198.1	83.2	35.0	48.2	42.0
June 3	141	66	280.1	145.7	29.2	116.5	20.0
June 24	90	23	325.5	218.1	18.6	199.5[b]	8.5

[a]Data obtained at comparable periods for each planting.

[b]Plants not frosted until October 8.

Table 16. Relationship of planting date to flea beetle injury, 1944.

Date planted	Number of dustings[a]	Total yield bushels per acre	Per cent tubers rejected for flea beetle damage	"Good potatoes" bushels per acre[b]
May 20	6	160	85.1	24
June 1	5	184	87.5	23
June 20	5	292	6.4	273

[a]Cryolite-sulfur dust used for all applications.

[b]Potatoes free of flea beetle injury or damage not sufficiently severe to throw them out of U. S. No. 1 grade.

Table 17. Number of stolons per plant, the per cent infested and destroyed by larvae of *Epitrix tuberis* and yield in plots of potatoes planted on three different dates.[a]

Date of planting	Average number stolons per plant	Average per cent stolon tips infested	Average per cent stolon tips destroyed	U. S. No. 1 size potatoes per acre
May 22	11.7	73.6	29.4	83.4
June 3	14.5	62.3	10.4	205.2
June 24	15.6	24.1	2.2	211.2

[a]The mean average figures shown in the first column are not statistically significant; those in the second, third and fourth columns are highly significant.

stolons per hill in the later plantings, the differences were not statistically significant. However, the number of stolons infested and destroyed in the different plots was highly significant. In the May 22 planting almost 30 per cent of the stolon tips were completely destroyed by the feeding activities of the larvae, whereas only 10 and 2 per cent were so affected in plots planted on June 3 and June 24, respectively. Since the potato plant usually produces an excess of stolons, the loss of a few probably has little effect on the crop. When 30 per cent of the potential tuber-forming parts are destroyed the yield most certainly is reduced. Yields for the three plantings also are given in Table 17.

Location of fields

Not only are flea beetle populations higher, foliage injury more severe and tuber damage greater in early plantings, but such plantings also have a marked influence on the beetle population and injury in nearby late fields.

It has been observed repeatedly that the more heavily infested late plantings have been located near early fields. The influence of early plantings on the flea beetle population in nearby late fields, as determined by sweep net samples, is illustrated in Fig. 12. A comparison of the tuber quality in these same fields is presented in Table 15. Thus the location of late planted fields with respect to earlier plantings is a factor of considerable importance in the flea beetle control program.

Table 15. Comparison of tuber quality in six late planted fields as influenced by the presence or absence of nearby early plantings.[a]

Location	1940 Per cent "good potatoes"[b]		1941 Average number flea beetle blemishes per tuber[c]	1942 Per cent "good potatoes"[b]	
	Treated plots	Untreated plots		Treated plots	Untreated plots
No early field nearby	88.7	21.3	19.0	90.2	89.7
Near early field	44.1	5.2	33.9	42.9	4.4

[a]Beetle populations of these fields shown in Fig. 12.

[b]"Good potatoes" refers to tubers free of flea beetle damage or damage not sufficiently great to throw them out of U. S. No. 1 grade.

[c]1941 figures based on samples of tubers picked at random over each field shortly after harvest.

Destruction of cull dumps and volunteer potato growth

Cull potatoes should not be left to sprout in piles about the farm or in public dumping places. Volunteer growth can be prevented by proper disposal of such tubers. This can be accomplished by burying the potatoes at a depth of two or more feet, or by scattering them thinly over the surface

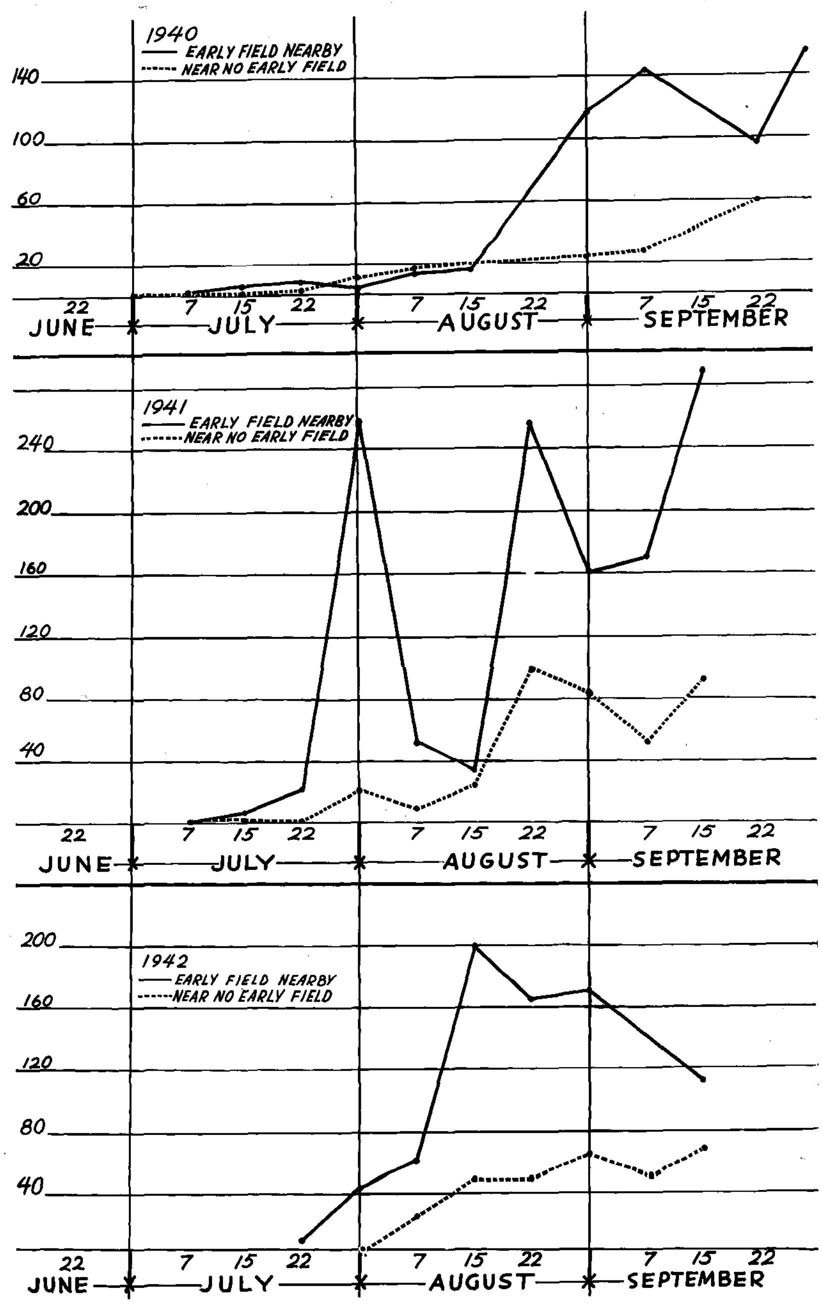


Fig. 12. Adult flea beetle populations in six late planted fields as influenced by the presence or absence of nearby early plantings. The sharp drop in the 1941 population curve (heavy line) is due to the fact that the field was dusted with Dutox on August 4. Figures on the left refer to average number of beetles collected per 100 sweeps of net. See Table 18 for comparison of quality of tubers produced in these fields.

of the ground. Weed burners, weedicides, salt, and waste crankcase oil also have been used with some success.

Weed control

Although destruction of wild host plants undoubtedly would be of some value as a control measure for tuber flea beetles in Nebraska, data already presented indicate that these plants are of comparatively little importance in the build-up of injurious populations. Nevertheless, weed eradication is a commendable practice on any farm and the elimination of solanaceous weeds, which serve as breeding hosts, is advisable.

Resistant varieties

The possibility that potato varieties differ in their resistance to damage by flea beetle larvae was investigated in 1941. That year two test plots, each containing eight varieties, were planted at the Scotts Bluff Substation on different dates, June 1 and June 20. At harvest time random samples of 12 tubers (between 2 and 2 1/2 inches in diameter) of each variety were taken from both plots.

A peeling method was used to measure the amount of larval damage present. Each potato was weighed on a gram scale, then carefully peeled so as to remove the skin, eyes and scab lesions. Following this, the tuber again was weighed and a second peeling made to remove the flea beetle "slivers." The amount pared away during the second peeling represented the actual loss due to flea beetle larvae. The results are summarized in Table 19.

Table 19. Varietal susceptibility to flea beetle damage as measured by tuber peeling method.[a]

Variety	Per cent additional loss due to second peeling of potatoes damaged by flea beetle larvae: June 1 planting	June 20 planting	Average
Triumph	5.7	4.2	5.0
Katahdin	7.6	3.1	5.4
Kasota[b]	7.6	3.7	5.6
Red Warba	8.2	3.6	5.9
Cobbler	8.5	7.4	8.0
Chippewa	11.5	5.8	8.6
Mesaba	11.6	5.5	8.6
B-4-1	16.2	7.1	11.6
Difference required for significance at 19 to 1 odds	3.2	c	2.2

[a]Tubers were weighed and peeled in the usual way, then weighed and peeled again to remove flea beetle "slivers." The per cent loss necessitated by the second peeling thus represents the actual flea beetle damage.

[b]When the test was made (in 1941) this variety was known as B-5.

[c]Differences in June 20 planting were not statistically significant.

The varieties may be assigned to three groups on basis of susceptibility: Most resistant, Triumph, Katahdin, Kasota and Red Warba; medium resistant, Cobbler, Chippewa and Mesaba; and least resistant, the experimental line designated as B-4-1. It is interesting to note that the Triumph, the most widely grown variety in western Nebraska, ranked lowest in amount of injury present and that the next two most popular types, the Katahdin and Kasota, ranked second and third, respectively.

Time of harvest

Landis (54) and Fulton and Glendenning (26) have advocated early harvest as a means of preventing late season larval injury to the crop. This is also a good practice to follow in Nebraska, as is indicated by the data presented in Table 20. Highly significant increases in amount of flea beetle larval injury occurred in a June 24 planting from September 11 to October 2 in plots that had been sprayed with zinc arsenite as well as in the untreated checks. However, the difference in amount of damage present

Table 20. Increase in amount of larval injury occurring from September 11 to October 2, 1943, in a June 24 planting of potatoes as measured by tuber peeling method.[a]

Comparison	Date of harvest	Treatment of plot[b]	Average per cent additional loss due to second peeling of tubers	Per cent difference in comparisons
1.	Sept. 11	Sprayed	0.99	1.99[c]
	Sept. 11	Check	2.98	
2.	Sept. 11	Sprayed	0.99	4.83[c]
	Oct. 2	Sprayed	5.82	
3.	Sept. 11	Check	2.98	3.48[c]
	Oct. 2	Check	6.46	
4.	Oct. 2	Sprayed	5.82	0.64
	Oct. 2	Check	6.46	

[a]See footnote a Table 19.

[b]Treated plots sprayed with zinc arsenite (2-40).

[c]Highly significant difference (P= 0.01).

in the treated and check plots on September 11 largely had disappeared by October 2 (comparisons 1 and 3, Table 20). Such indicates that in these small plots the last spraying (made on August 17) did not for long prevent the reëstablishment of a beetle population from adjacent check plots. It was interesting to note that the increase in larval blemishes recorded on October 2 was due to greater numbers of "pimples" and "slivers," there being practically no addition to the number of "tracks."

Insecticidal Control

Objectives and general plan of investigations

Field experiments were designed primarily to determine, first, the relative effectiveness of certain insecticides which previously had proven promising in controlling potato flea beetles, and second, the practicability of using insecticides in the form of dusts under western Nebraska conditions.

Since larval injury to tubers rather than foliage injury by adults is of first importance, control must be aimed at preventing adult beetles from laying eggs. The first spray or dust was applied when the plants were 3 to 6 inches high, and then repeated at one to two-week intervals, depending upon severity of the infestation. Arsenical and fluorine sprays were prepared at the rate of 2 pounds of the insecticide to 49 gallons of spray and applied at the rate of 100 to 125 gallons per acre. The dust mixtures, consisting of either one part of Dutox[1] or cryolite and four parts of dusting sulfur, were applied at the rate of 30 to 35 pounds per acre. In this way approximately 6 pounds of Dutox or cryolite were used on an acre at each application. Rotenone was applied as a 0.5 per cent dust. Wheat flour was used as the diluting agent for dust mixtures in some of the first experiments.

[1]A commercial product said to contain 72 per cent barium fluosilicate and 8 per cent sodium flualuminate.

During the early stages of the work, grower-owned sprayers developing 300 pounds pressure, with three nozzles per row, were used for making spray applications and dusts were applied either with a rotary hand duster or a grower-owned power duster (as was the case in 1941). Later a two-row self-propelled power sprayer, also developing 300 pounds of pressure and with three nozzles per row, and a four-row power duster were obtained for use on the project. Field experiments were conducted either in commercial potato fields in the Scottsbluff area, or in plantings at the Scotts Bluff Substation located about 6 miles east of Mitchell (Fig. 13).

Evaluation of experimental results

Three methods were used for measuring the experimental results: First, adult flea beetle populations were determined by counting the adults collected in a given number of sweeps with a 15-inch insect net; second, foliage damage by adult flea beetles was estimated by counting feeding holes in representative samples of leaves; and third, tuber quality was determined by grading samples of tubers on the basis of the amount of larval injury present. Usually tuber quality in the various experiments was measured as "per cent good potatoes." The term "good potatoes" as herein used (in tables as well as text) refers to tubers free of flea beetle damage or damage not sufficiently great to throw them out of U. S. No. 1 grade. Total yield records were taken in most instances, but since differences between plots usually were not significant, such data proved to be of limited importance in the evaluation of results. The data secured have been analyzed statistically by the analysis of variance method, except in a few instances where the results did not lend themselves to this type of treatment.

Fig. 13. Applying insecticides to potatoes in Scotts Bluff County with power duster (above) and power sprayer (below).

Control experiments, 1940

In 1940 field experiments were conducted on two farms near Gering. Field A was planted on June 3 and 4. Treatments were replicated three times in eight-row plots approximately 500 feet long. Four applications were made, on June 21, and July 3, 18 and 29, the first being applied when the plants were 3 or 4 inches high.

A summary of results of the various treatments in this field is shown in Table 21. All treatments were superior to checks. Zinc arsenite and basic copper arsenate sprays and Dutox dust were about equally effective, and all were better than cryolite or Dutox sprays. Calcium arsenate-Bordeaux spray occupied an intermediate position between the least and most effective materials.

Table 21. Adult population of tuber flea beetle, foliage injury and yield of "good potatoes" following various treatments, based on the means of three replications, 1940.
Field A - Planted June 3 and 4.

Treatments	Number potato flea beetles per 50 sweeps[a]	Average number holes per leaf[b]	Per cent "good potatoes"[c]
Zinc arsenite spray, 5-100	3.2	8.7	89.5
Cryolite spray, 5-100	3.3	23.1	85.1
Calcium arsenate-Bordeaux spray, 4-4-12-100	2.6	13.3	88.1
Basic copper arsenate spray, 5-100	2.5	10.7	86.9
Dutox spray, 5-100	2.8	18.2	86.4
Dutox-flour dust, 1-4	2.8	10.9	92.7
Untreated check	13.9	58.2	44.0
Difference required for significance at 19 to 1 odds	1.2	9.7	9.9

[a]Average of 1,200 sweeps per plot taken as 50-sweep samples each week from June 29 to August 26 and again on September 19.

[b]Average for 60 leaves collected from each plot between August 6 and 8.

[c]Based on 150-pound samples from each plot.

Field B was planted June 12. Treatments were replicated three times in eight-row plots approximately 490 feet long. Applications were made on July 8, 18 and 30, and on August 10. After spraying was discontinued in mid-August, a migration of potato flea beetles from an adjoining early field almost completely obliterated any population difference between plots.

A summary of the results of this test is presented in Table 22. A significant difference between treated and untreated plots is clearly evident.

Table 22. Adult population of tuber flea beetle, foliage injury, and yield of "good potatoes" following various treatments, based on the means of three replications, 1940.

Field B - Planted June 12

Treatments	Number potato flea beetles per 50 sweeps[a]	Average number holes per leaf[b]	Per cent "good potatoes"[c]
Zinc arsenite spray, 5-100	2.9	10.9	27.0
Dutox-flour dust, 1-4	1.8	10.8	21.5
Dutox spray, 5-100	3.2	18.3	18.6
Cryolite spray, 5-100	2.6	15.9	18.2
Untreated check	7.6	35.1	5.2
Difference required for significance at 19 to 1 odds	2.3	3.2	13.5

[a]Average of six 50-sweep samples taken from each plot during spray season, or from July 12 to August 14.

[b]Average for 60 leaves collected from each plot August 28.

[c]Based on 120-pound samples from each plot.

Zinc arsenite spray and Dutox dust were equally effective, and on the basis of foliage injury both were superior to Dutox and cryolite sprays. Only 18 to 27 per cent of the tubers in the treated plots were graded "good" as compared to 85 to 92 per cent in Field A. Conditions between the two experiments differed markedly in that Field B was bordered by an early planting which was heavily infested with flea beetles, whereas Field A was effectively isolated from early potatoes. As the vines in the early field matured and died, first generation flea beetles migrated into Field B in great numbers. The results of this test, along with data presented in Table 18, show the difficulty of obtaining satisfactory control with insecticides in late fields located near early plantings.

Some records were obtained from an early commercial planting near Gering (Field C). This was not originally planned as an experiment, but was a limited field test started after a heavy flea beetle population appeared. Two materials, zinc arsenite and Dutox sprays, were used in 18-row plots, approximately 400 feet long and replicated twice. Four sprays were applied, on June 11 and 20, and July 8 and 18.

Results of the test in Field C are summarized in Table 23. Zinc

Table 23. Adult tuber flea beetle population, foliage injury, and yield of "good" and cull potatoes following treatment with zinc arsenite and Dutox sprays, based on the means of two replications, 1940.

Field C - Planted early May

Treatments	Average number adults per 50 sweeps[a]	Average number holes per leaflet[b]	Per cent "good potatoes"[c]	Per cent "culls"	Yield pounds[d]
Zinc arsenite spray, 5-100	9.1	5.9	32.3	19.2	220.0
Dutox spray, 5-100	19.1	10.1	4.2	56.5	212.0
Untreated check	46.3	21.2	0.0	87.5	135.5

[a]Six 100-sweep collections taken from each plot between June 12 and July 7.

[b]Average for 60 terminal leaflets secured from each plot on July 13.

[c]Based on tubers from center row of each plot.

[d]Average yield per center row of each plot.

arsenite spray was superior to Dutox spray. Severe foliage damage probably accounted for the difference in yield between treated and untreated plots. As shown by the low percentage of "good potatoes" in treated plots, poor or unsatisfactory control was obtained in spite of the fact that four sprays were applied. This experiment illustrates results frequently obtained by growers in their efforts to control flea beetles in early planted fields.

Control experiments, 1941

An experiment was conducted in 1941 on an April 24 planting near Mitchell. Treatments were replicated six times in a Latin square arrangement on eight-row plots 40 feet long. Four insecticide applications were made, on June 13 and 21, and July 2 and 18.

Results of this experiment are given in Table 24. All treatments

Table 24. Adult flea beetle damage to foliage, yield of "good potatoes," and total yield of potatoes following various treatments, based on the means of six replications, 1941.[a]

Field near Mitchell - Planted April 24

Treatments	Average number holes per leaf[b]	Per cent "good potatoes"[c]	Average yield pounds[d]
Zinc arsenite spray, 5-100	18.5	93.0	99.5
Zinc arsenite-lime sulfur spray, 5-2 1/2-100	20.4	96.3	108.8
Calcium arsenate-Bordeaux spray, 4-4-12-100	21.2	92.0	91.2
Dutox spray, 5-100	23.5	89.0	99.8
Dutox-sulfur dust, 1-4	16.0	93.8	101.0
Untreated check	37.9	67.2	90.8
Difference required for significance at 19 to 1 odds	5.7	7.7	10.6

[a]Adult population records were not obtained.

[b]Average for 24 leaves collected from each plot during period July 28 to August 2.

[c]Based on 50-pound samples from each plot.

[d]Average yield four center rows per plot.

significantly increased the degree of control over untreated checks on the basis of foliage damage and quality yield. Zinc arsenite-lime sulfur spray gave a significant increase in total yield. On the basis of total yield, zinc arsenite-lime sulfur spray was better than calcium arsenate-Bordeaux mixture spray, and Dutox (both dust and spray) and zinc arsenite spray showed a superiority over calcium arsenate-Bordeaux closely approaching significance. It is of interest to note that, although planted early, effective control was obtained in this field.

Another test was conducted in a field planted June 20 near Scottsbluff. Treatments were replicated four times in six-row parallel plots 630 feet long. Materials were applied on July 22, August 6 and August 21.

Results of this test are shown in Table 25. The treatments gave a

Table 25. Adult flea beetle population, foliage injury, and yield of "good potatoes" following various treatments, based on the means of four replications, 1941.

Field near Scottsbluff - Planted June 20

Treatments	Average number adults per 50 sweeps[a]	Average number holes per leaf[b]	Per cent "good potatoes"[c]
Zinc arsenite-liquid lime sulfur, 5-2 1/2-100	6.9	11.6	90.0
Dutox-dusting sulfur, 93-95 per cent 325 mesh, 1-4	5.0	15.1	92.2
Untreated check	19.3	31.9	20.8
Difference required for significance at 19 to 1 odds	7.9	13.0	14.7

[a]Average based on 100-sweep samples of second generation adults taken in each plot on September 10.

[b]Based on 40-leaf samples examined from each plot early in September.

[c]Based on 100-pound samples from each plot.

significant reduction of flea beetles and foliage injury. As was true in the experiment conducted near Mitchell, high percentages of "good potatoes" were obtained in treated plots in contrast to the checks. There was no difference in the effectiveness of the two treatments (zinc arsenite spray and Dutox dust), a fact which supports previous and succeeding tests.

Control experiment, 1943

In 1943 a test was conducted at the Scotts Bluff Substation in a field planted June 17 and 18. Parallel eight-row plots approximately 175 feet long, replicated three times, were used. A total of five insecticide applications was made, July 12, 20, 29, and August 6 and 16.

Results of this experiment are presented in Table 26. The flea beetle

Table 26. Adult flea beetle population, foliage injury, and larval damage to tubers following various treatments, based on the means of three replications, 1943.

Scotts Bluff Substation - Planted June 17 and 18

Treatments	Total number flea beetles per 1200 sweeps[a]	Average number holes per leaf[b]	Per cent tubers with no larval damage[c]
Dutox-sulfur dust, 1-4	70	10.1	35.3
Cryolite-sulfur dust, 1-4	51	10.3	38.3
Cryolite-rotenone-sulfur dust, 20-10 (5 per cent)-70	63	9.0	44.3
Rotenone-sulfur dust, 1 (5 per cent) -9	68	11.0	31.2
Zinc arsenite-liquid lime sulfur spray, 5-2 1/2-100	97	9.8	36.0
Untreated check	375	18.4	25.4
Difference required for significance at 19 to 1 odds	45.6	4.1	10.1

[a]Collected during spray season, July 24 to August 19, and from September 20 to October 4.

[b]Thirty leaves collected from each plot on September 6.

[c]Based on 50-pound samples from each plot.

population in this field remained at a low level throughout the season, as indicated by the relatively small number of beetles taken in 1,200 sweeps. Since larval damage to tubers was light, tubers were graded on the basis of "having or not having" larval injury. Significant differences between treated and untreated plots were obtained. In general, Dutox-sulfur dust, cryolite-sulfur dust and zinc arsenite-lime sulfur spray were about equally effective, whereas the cryolite-rotenone-sulfur combination was slightly superior to any of the materials tested. Rotenone-sulfur alone appeared to be somewhat less effective than the other materials. This probably resulted from the fact that the residual toxicity of rotenone was not as great as that of Dutox, cryolite and zinc arsenite.

Control experiments, 1944

In 1944 two field experiments and one insectary test were conducted at the Scotts Bluff Substation for the purpose of determining the relative effectiveness of DDT (dichloro-diphenyl-trichloroethane) and locally recommended insecticides for controlling tuber flea beetles. These experiments are described briefly in the following three paragraphs.

A field of Triumph potatoes (Field A) planted May 19 was used for this experiment. Treatments and untreated checks were replicated four times in parallel eight-row plots 150 feet long. Applications of dusts and sprays were made with power equipment on June 15 and 23, and July 3, 13 and 24. The insecticides used were: (1) Three per cent DDT dust in pyrophyllite, (2) DDT spray containing 4 pounds of 10 per cent DDT in pyrophyllite in 100 gallons of water, (3) cryolite-sulfur dust (1 to 3 by weight), (4) basic copper arsenate-sulfur dust (1 to 4 by weight), and (5) zinc arsenite-wettable sulfur spray (5 and 10 pounds, respectively, to 100 gallons of water). All of these materials with the exception of DDF were commercial products commonly sold for use on potatoes and other crops. Dusts were used at the rate of about 35 pounds and sprays 125 gallons per acre per application.

A second test (Field B) was designed to compare the effectiveness of a 3 per cent DDF dust in pyrophyllite and a 5 per cent o-nitrodiphenyl dust containing 90 per cent Pyrax ABB and 5 per cent Celite. The treatments, replicated three times, were made in a small July 1 planting of Triumphs which had been blocked out in four-row plots 30 feet long. Dust applications were made with a rotary hand duster from each side of the row on July 30, August 7, 15 and 26, and September 2.

The third experiment was designed to determine the relative effectiveness, under insectary conditions, of the four dust mixtures tested in field experiments A and B. Potato leaflets treated with uniform amounts of the various dusts were placed in small 30-mesh screen wire cages each of which contained 20 flea beetles. Five replications of 20, or a total of 100 beetles, were exposed to each material. A check cage supplied with an untreated leaflet accompanied each replicate. After 24 hours of exposure to the dusted leaflets a fresh untreated one was added to each cage. Daily thereafter these were changed so that fresh food was available at all times, but the original dusted leaflets were left in the cages for the entire 112 hours of the experiment. When fresh food was supplied, dead beetles were removed and counted. During the course of this experiment the laboratory temperature fluctuated from about 59 degrees Fahrenheit early in the morning to about 77 degrees Fahrenheit during the middle of the day.

The results of these three tests have been summarized in Tables 27, 28 and 29. In field experiment A all insecticidal combinations markedly reduced populations of tuber flea beetles, but DDT, both as a spray and dust, was significantly better than each of the other treatments. Similar results

Table 27. Tuber flea beetle population, foliage injury, and yield following various treatments, based on means of four replications, 1944.

Scotts Bluff Substation, Field A - Planted May 19

Treatments	Number flea beetles per 50 sweeps	Number newly emerged flea beetles per 350 sweeps	Number feeding punctures per leaf[b]	Yield U. S. No. 1 and 2 potatoes, bushels per acre[c]
Three per cent DDT-pyrophyllite dust	21.3	10.5	27.5	116
Cryolite-sulfur dust, 1-3	48.2	32.2	53.7	106
Basic copper arsenate-sulfur dust, 1-4	61.9	30.2	53.2	90
DDT spray, 0.4-100	28.4	11.8	54.5	79
Zinc arsenite-wettable sulfur spray, 5-10-100	68.5	43.8	68.5	83
Difference required for significance at 19 to 1 odds[a]	14.8	13.5	17.9	not sig.[d]
Untreated check	176.1	108.5	156.2	60.9

[a]Means for untreated check plots omitted from these calculations.

[b]Average for 50 leaves collected per plot (or average of 200 leaves per treatment) on July 28.

[c]Based on yield of 100-foot strip in four center rows of each plot.

[d]Yields obtained with DDT dust and cryolite-sulfur dust were significantly better than check.

Table 28. Tuber flea beetle foliage injury and yield of "good potatoes" following various treatments, based on means of three replications, 1944.

Scotts Bluff Substation, Field B - Planted July 1

Treatments	Number feeding punctures per leaf[a]	Per cent U. S. No. 1 size tubers graded as "good"[b]	Number bushels "good" potatoes per acre[b]
Three per cent DDT-pyrophyllite dust	15.5	69.7	155.7
Five per cent o-nitrodiphenyl dust	46.3	16.9	19.4
Untreated check	53.4	10.2	11.0
Difference required for significance at 19 to 1 odds	14.0	21.0	62.2

[a]Average for 30 leaves collected from each plot on August 31.

[b]Based on yield of two center rows from each plot.

Table 29. Mortality of tuber flea beetles in insectary test, based on means of five replications, 1944.

Treatments	Number dead flea beetles per cage	Actual per cent mortality	Per cent mortality transformed to degrees (anglemarcsine √percentage)
Three per cent DDT-pyrophyllite dust	16.2	81	70.6
Cryolite-sulfur dust, 1-3	8.2	41	39.6
Basic copper arsenate-sulfur dust, 1-4	4.4	22	27.2
Five per cent o-nitrodiphenyl dust	0.4	2	5.2
Untreated check	0.4	2	3.7
Difference required for significance at 19 to 1 odds			17.1

were obtained in field experiment B. Where DDT dust was used there were significant reductions in numbers of flea beetles and feeding punctures on leaves. Likewise, the increased yield, as expressed in percentage of marketable size tubers, average weight of marketable tubers and number of bushels of "good potatoes" per acre, was significant for plots treated with DDT dust. The o-nitrodiphenyl dust was ineffective. Under conditions of the insectary test, flea beetle mortality on foliage treated with DDT dust was almost twice as great as on foliage treated with cryolite-sulfur and from three to four times greater than that obtained with basic copper arsenate-sulfur. O-nitrodiphenyl dust again was ineffective.

Control experiments, 1945

A field experiment designed to compare the effectiveness of three dusts containing 2.5 per cent DDT (1, mechanically mixed with 300-mesh sulfur; 2, mechanically mixed with pyrophyllite; and 3, fused with sulfur) and the standard cryolite-sulfur dust (1 to 3 by weight) was conducted in 1945 at the Scotts Bluff Substation in a June 22 planting. The plots were eight rows wide and 150 feet long. All dust mixtures were applied with power dusters at the rate of approximately 35 pounds per acre four times during the season. Each treatment was replicated four times. The flea beetle infestation was relatively light and the results obtained with the four dusts were not significantly different. However, all were effective and statistically superior to the untreated checks (Table 30).

In another test a dust containing 3 per cent DDT in pyrophyllite and one containing 1 per cent DDT fused with sulfur gave similar degrees of control when measured by sweeping the plots 24 hours following the application.

Table 30. Tuber flea beetle population, foliage injury, and yield of "good potatoes" following various treatments, based on means of four replications, 1945.

Scotts Bluff Substation - Planted June 22

Treatments	Average number flea beetles in 400 sweeps of net	Average number feeding punctures per leaf[a]	Per cent U. S. No. 1 size potatoes graded as "good"[b]
Two and one-half per cent DDT-sulfur dust (mech. mix)	13.0	3.62	93.6
Two and one-half per cent DDT-sulfur dust (fused)	14.2	3.90	93.8
Two and one-half per cent DDT-pyrophyllite dust	26.8	6.73	82.2
Cryolite-sulfur dust, 1-3	19.8	5.21	93.6
Untreated check	124.5	17.06	52.8
Difference required for significance at 19 to 1 odds	20.7	3.98	17.9

[a]Based on 50-leaf samples from each plot.

[b]Based on yield of four center rows from each plot.

However, the DDT-fused sulfur dust remained more effective over a period of several days and continued to kill many newly developed beetles as they emerged from the soil. A 1 per cent DDT in pyrophyllite dust gave unsatisfactory control (Table 31). In this experiment the dusts were replicated

Table 31. Comparison of the residual toxicity of three DDT dusts under field conditions at the Scotts Bluff Substation, 1945.

Treatments	Average number flea beetles per 100 sweeps before dusting	Average number flea beetles per 100 sweeps at intervals after dusting		
		1 day	5 days	11 days
Three per cent DDT-pyrophyllite dust	88	1	44	209
One per cent DDT-pyrophyllite dust	130	35	87	277
One per cent DDT-fused sulfur dust	97	3	4	45

twice in somewhat isolated one-fourth acre plots. The applications were made at the time first generation flea beetles began emerging from the soil, and the rate at which the plots were repopulated afforded an excellent opportunity to measure the effectiveness of the three dusts. Eleven days after treatment the population had risen to over 46 per cent of the original number in the DDT-fused sulfur plots as compared to increases of over 200 per cent in plots dusted with DDT-pyrophyllite.

In 1945, for the first time in Nebraska, airplanes were used for the application of insecticides to potato fields. At the Scotts Bluff Substation a preliminary test was conducted for the purpose of comparing the effectiveness of DDT dusts applied by airplane and ground machinery. The plane used was a Navy N-3-N trainer (Fig. 14). Both methods of application resulted in excellent kills of tuber flea beetles as measured by sweep-net collections 24 to 30 hours after dusting. Observations in several commercial fields which had been dusted with the above-mentioned plane also revealed that this method of applying a 3 per cent DDT dust gave good results against the tuber flea beetle.

<u>Timing and number of applications for effective control</u>

An experiment was conducted at the Scotts Bluff Substation in 1944 to determine the number of dustings needed to control tuber flea beetles in a typical late planted field, and to evaluate (in sequence) the relative importance of the various insecticide applications.

The experimental field, a June 20 planting, was divided into 40 eight-row plots. Four applications of a cryolite-sulfur (1 to 3 by weight) dust were made on July 17 and 28, and August 8 and 19. Some plots received only

Fig. 14. Application of DDT dusts by airplane, Scotts Bluff County, 1945.

the first, second, third or fourth applications, others were given all four or combinations of these. In all there were 10 different schedules in this test. The plan followed is shown in Table 32. From this table it is evident that schedule 1 involved only the first application. Similarly, plots receiving schedule 6 were dusted twice, or received the second and third dustings, whereas all four applications were given in schedule 4 and only the fourth, or August 19, dusting in schedule 10, and so on. Each of the ten schedules was replicated in four plots in the field.

Table 32. Plan of experiment to determine time and number of dust applications necessary to control the tuber flea beetle.

Date of applications	Schedules[a]									
	1	2	3	4	5	6	7	8	9	10
No. 1 - July 17	X	X	X	X						
No. 2 - July 28		X	X	X	X	X	X			
No. 3 - August 8			X	X		X	X	X	X	
No. 4 - August 19				X			X		X	X

[a]X indicates the number and sequence of applications followed in the 10 different schedules.

The results, listed in Table 33, show that the best control was obtained in plots receiving schedules 4, 7 and 9. This indicates that the highest degree of control is secured from a program involving several applications. The differences between the three above mentioned treatments were not significant. Results obtained in plots receiving single applications show that the later dustings were of greater value than those made earlier. The importance of late applications is further emphasized by the fact that the combination of applications 3 and 4 ranked ahead of 2 and 3 and 1 and 2.

Table 33. Summary of results of field test to determine time and number of dust applications necessary to control the tuber flea beetle.

Schedule number	Number and sequence of applications[a]	Average number feeding punctures per leaf[b]	Average number "worm tracks" and "pimples" per pound of potatoes[c]
4	1, 2, 3 and 4	2.8	8.4
9	3 and 4	3.6	6.7
7	2, 3 and 4	4.5	10.8
3	1, 2, 3	5.0	12.7
6	2, 3	5.1	12.5
10	4	5.2	18.4
2	1, 2	5.8	19.9
8	3	6.7	18.0
5	2	6.9	18.5
1	1	7.6	25.9
Difference required for significance at 19 to 1 odds		2.1	10.6

[a]Number and date of application: 1 - July 17, 2 - July 28, 3 - August 8, and 4 - August 19.

[b]Based on 40-leaf samples from each plot.

[c]Approximately 35 pounds of tubers were examined from each plot.

Although the flea beetle population in this particular field was relatively low, it was representative of the average June 20 planting with respect to incidence and general development of the infestation. The major difference in populations usually noted between individual fields is principally one of degree or size. Therefore, it is reasonable to assume that similar results would have been obtained in this test had the infestation been considerably heavier. Under such conditions the differences between the best and poorest treatments probably would have been greater and the practical value of the better schedules made more apparent.

Soil application of DDT

The possibility of reducing flea beetle injury to tubers, by soil applications of DDT, was investigated at the Scotts Bluff Substation in 1945. A thin band of DDT dust was placed down the test rows below the surface of the soil and above the seed pieces. By removing the outer disks on the planter the seed pieces were covered with only a shallow layer of soil, varying in depth from 1 to 2 inches. Soon after planting, the band of dust (about 10 inches wide) was placed along the row above the seed piece. A metal tube, flattened and fan-shaped on one end, served as an applicator. By gently tapping the tube as it was moved down the row a fairly uniform band of dust was deposited. Immediately following the DDT application a disk cultivator was used to throw a ridge of soil up over the layer of insecticide.

The treatments, DDT-pyrophyllite dusts containing 3, 6 and 10 per cent DDT, were replicated four times in a Latin square design in four-row plots 30 feet long. Each dust mixture was used at the uniform rate of 300 pounds per acre so that the amount of DDT actually applied was 9, 18 and 30 pounds per acre. As may be seen from Table 34, all three treatments significantly reduced the amount of larval damage to the tubers. Potatoes from plots receiving 30 pounds of DDT to the acre were of slightly better quality than those harvested from plots where 9 pounds had been used. However, the degree of freedom from flea beetle damage was so low in all plots that the results cannot be considered of value economically. The data indicate that different DDT formulations and/or better methods of application, such as the use of properly adjusted fertilizer attachments on the planter, might produce results of value. No evidence of injury to potato plants was observed.

Table 34. Effect of soil applications of DDT on the amount of flea beetle larval damage to potatoes at Scotts Bluff Substation - 1945

Treatments	Number pounds DDT applied per acre[a]	Average per cent U. S. No. 1 potatoes
Three per cent DDT-pyrophyllite dust	9	14.4
Six per cent DDT-pyrophyllite dust	18	18.8
Ten per cent DDT-pyrophyllite dust	30	22.8
Untreated check	0	3.4
Difference required for significance at 19 to 1 odds		8.1

[a]All mixtures applied at uniform rate of 300 pounds per acre below the surface of the soil and from 1 to 2 inches above the seed piece at planting time (June 2).

Relationship of Flea Beetle Control to the Control of other Potato Insects

Although the tuber flea beetle is the most important potato pest in the irrigated section of the North Platte Valley, other insects are present and all must be considered in the development of a control program for any one form. Practices effecting control of one insect should not be followed if by so doing conditions are made favorable for the increase of some other injurious species.

Effect of insecticides on aphid populations

During the 1941 growing season, field observations indicated that aphids, *Myzus persicae* (Sulz.), were becoming abundant in experimental potato plots that had been sprayed with zinc arsenite-lime sulfur. At that time this spray combination was widely used in western Nebraska to combat tuber flea beetles and the potato psyllid, Paratrioza cockerelli (Sulc). Since there is a large acreage of potatoes grown with a view to certification in this area, control measures that tend to increase aphids might have important economic implications because of the role these insects play in the dissemination of virus diseases. Consequently, in 1942, additional investigations were undertaken in an effort to determine more clearly the effects of the different treatments on the aphid populations.

The results of these experiments (41) showed that highly significant aphid population increases occurred on plants treated with zinc arsenite spray, especially when two or more applications were made. Sometimes slight increases occurred following the use of barium fluosilicate (Dutox) dust, but in a majority of the tests no significant increases were found where this material was used.

In 1945 sweep-net records taken in experimental fields showed aphid counts to range from 9 to 47 in plots treated with a 2.5 per cent DDT dust as compared to 126 where the standard cryolite-sulfur dust was used and 186 in the untreated checks. This evidence, along with similar data obtained in 1944, indicated that DDT could be used without building up the aphid population as was generally the case following the use of zinc arsenite.

Effect of DDT on the biological balance

The possibility that widespread use of the potent DDT might upset the biological balance and create new problems was given some attention. Tests conducted in 1944 showed that DDT could be used effectively to control all the major pests of the potato, except possibly the grasshopper, in Nebraska (39). In these experiments it also was found that DDT reduced the number of beneficial insects such as *Nabis* spp., *Orius* spp. and lady beetles.

In 1945 four neighboring commercial potato growers near Scottsbluff cooperated in a large scale test. All potato fields on the four farms were treated from four to five times with a 3 per cent DDT-pyrophyllite dust. Insect collections were made at regular intervals throughout the summer in each of the treated fields and also from nearby plantings on surrounding farms which had been treated with the standard cryolite-sulfur dust. The DDT-treated fields were noticeably "free" from insects. General observations also were made on the insect populations of adjoining crops, alfalfa, sugar beets, corn and garden vegetables, in order to determine if outbreaks or increases of other species occurred as a result of the destruction of predatory and parasitic insects. Insofar as could be determined no increases of harmful insects occurred. Although some beneficial species were killed in treated fields, this did not appear to have any appreciable effect on the insect problem as a whole.

Effect of agronomic practices

Agronomic or cultural practices found to be effective control measures for tuber flea beetles also aid in the control of most other pests of the potato in western Nebraska. Data collected over the period of this study have shown repeatedly that the heaviest insect populations were present in early planted fields. This was especially true of the potato psyllid. In favorable seasons large numbers of psyllids developed in early plantings and later migrated into the late planted fields. Hence the late date of planting is as important a control measure for psyllids as it is for flea beetles. The same is true with respect to location of fields and the presence or absence of cull dumps. In fact, no evidence is available to show that the cultural practices found to be of value in the control of flea beetles contribute to the increase of other potato insects in Nebraska.

DISCUSSION

Data obtained in the course of these investigations show that damage by the tuber flea beetle can be greatly reduced in western Nebraska by a control program combining cultural methods and the use of insecticides. This program includes: (1) The elimination of early potato plantings, (2) the prevention of volunteer growth on cull dumps, (3) planting the late crop as late as is practical, preferably after June 15, and (4) the timely application of three to five DDT dusts or sprays.

Western Nebraska is essentially a late potato region, for less than 10 per cent of the potato acreage is planted early. In those localities where early planted potatoes are grown, the overwintered flea beetles are provided with an abundance of excellent food soon after emerging from hibernation. The large populations of first generation beetles developing on these potatoes subsequently migrate to late planted fields and produce the second generation larvae which cause serious economic losses to that crop. However, in localities where early potatoes are not grown, overwintered individuals are forced to feed on the less nutritious and more widely scattered food plants which also are less favorable for larval development. As a result, the beetle population in late fields in such areas remains relatively low throughout the season.

The food plant study reported in this thesis indicates that the elimination of all early plantings of potatoes would lower the general population level of tuber flea beetles by reducing the longevity and reproductive capacity of the overwintered generation. The elimination of the relatively few acres of early potatoes would be practical and should involve only minor adjustments in the general farming program of a few individual potato growers. In fact, by destroying or preventing all early potato growth and by planting the crop as late as possible, growers will have taken advantage of the most effective and least expensive control measures available for combatting the tuber flea beetle.

Since larval damage to tubers is far more serious than foliage injury by the adults, it is necessary to apply insecticides sufficiently early to kill the beetles before they have deposited eggs. In this fact lies the reason potato growers often fail to secure satisfactory results. According to some earlier recommendations in Nebraska, the first insecticidal treatment should be made when the vines are 6 to 8 inches high. This generally is about two weeks late in early planted fields, for most of these are heavily infested with beetles from the time the plants emerge from the soil. Late planted fields ordinarily do not require the first application until the vines are about 6 inches high. Of relatively greater importance in late fields are the applications made in August, or just before the vines close the rows.

Dusts have proved equal to sprays in effectiveness. This is of considerable interest and importance because of certain advantages of dusting. The difficulty of moving heavy spray machinery in fields crossed by irrigation ditches or in recently irrigated fields, the inconvenience of obtaining water in some localities, and late season vine damage all tend to discourage growers from making necessary spray applications. These objections largely are overcome by the use of dusts. Dusting machines may be used later in the season with less vine injury and better coverage. However, dusts must be applied during periods of little wind movement, which usually necessitates application in the early morning, evening or at night. The presence or absence of dew on plants has little or no influence on the effectiveness of the dusts used in western Nebraska for flea beetle control.

DDT, the best material yet tested for potato insects, largely replaced zinc arsenite, basic copper arsenate, cryolite and barium fluosilicate during the 1946 season for flea beetles and liquid lime sulfur and wettable sulfur for psyllids. The use of DDT has simplified recommendations. At the present time (1946) a 3 per cent DDT-sulfur (or pyrophyllite) dust or a spray of 2 pounds of 50 per cent DDT to 100 gallons of water is recommended for potatoes. It no longer is necessary to use combination sprays or to add liquid lime sulfur or wettable sulfur to the spray for psyllids. Since blights seldom are serious in western Nebraska, plant pathologists are not recommending the addition of fungicides.

There is need for continued research, especially with respect to the most efficient use of DDT. Additional work on dosages and diluents is required, as well as further investigations to determine the number of applications necessary for controlling the various potato pests.

SUMMARY AND CONCLUSIONS

1. The tuber flea beetle, *Epitrix tuberis* Gentner, is the most important of the insect pests found on potatoes in western Nebraska, especially in the irrigated sections of the North Platte Valley. Tuber blemishes caused by the feeding activity of the larvae are major factors in lowering the quality of the potato crop.

2. This species, which until recently was considered the same as *E. cucumeris* (Harris), occurs in British Columbia, Washington, Oregon, Colorado, Wyoming and western Nebraska and apparently reaches the eastern limits of its range in Nebraska.

3. Tuber flea beetles overwinter in the soil in the adult stage. Relatively high average winter survivals were noted in cage studies, survivals of 18.7 and 17.4 per cent being recorded for the winters of 1940-41 and 1941-42, respectively.

4. Adults feed on foliage of a wide range of plants; 28 different species were recorded as adult hosts. Whenever potatoes were available, they were preferred. Injury to crops other than potatoes was negligible.

5. Pairing takes place any time of day and is most prevalent in the field during late June and early July, then again the latter half of August.

6. In the insectary the preoviposition period per female ranged from 5 to 6 days; the oviposition period from 35 to 57 days, averaging 44.7 days; and the number of eggs per individual ranged from 161 to 215, averaging 187. Eggs usually were deposited in batches of from 12 to 15 with intervals of 1 to 2 days elapsing between successive depositions.

7. Eggs are laid in the damp soil about the base of the host plants. The average duration of the egg stage ranged from 5.5 to 6.2 days.

8. Larval feeding is confined to the underground portions of the plant. "Worm tracks," "slivers" and "pimples" are caused by larvae feeding on tubers of the potato plant. In Nebraska these blemishes, resulting in low quality potatoes, are far more serious than foliage injury by the adults.

9. Members of the family Solanaceae are the most important larval food plants. Larvae were found to develop on seven different host plants.

10. In the insectary the average duration of the larval period ranged from 17.7 to 22.8 days.

11. The average length of the pupal stage varied from 5.8 to 11.2 days.

12. In the Scottsbluff area adults begin emerging from the soil about mid-May and continue to appear until late June or early July. The peak of emergence normally is reached shortly before mid-June. Soon thereafter overwintered beetles move into early planted potato fields. Eggs are laid in the soil around the base of the plants from late May until at least the latter part of July. About July 1, first generation adults begin appearing and attain greatest numbers in early fields during the latter half of July or in early August. During July and early August, when the early crop matures or is harvested, the beetles migrate to nearby late plantings. Here eggs are laid and from these develop the second generation larvae which largely are responsible for tuber injury to the late crop. The first adults of the second generation usually appear about August 10 and reach a peak of abundance sometime between late August and mid-September. In the North Platte Valley two fairly complete generations develop each year, and under some conditions evidence of a partial third has been obtained.

13. No parasites were discovered during this study. Predation of the adult flea beetles by *Collops* sp., *Nabis* sp. and a lacewing nymph was observed. A carabid, *Harpalus funestus*, frequently was found in the soil under conditions strongly suggesting that it serves as a predator of the immature stages.

14. Larval injuries to the tuber often are intensified by the invasion of scab and rhizoctonia organisms. The adult beetles serve as vectors of spindle tuber and unmottled curly dwarf. Based on casual observations, no close relationship exists between adult feeding punctures and early blight lesions in western Nebraska.

15. Factors found to be of most importance in influencing the abundance of tuber flea beetles are weather conditions, especially rainfall, irrigation, host plants, date of planting the potato crop and the presence or absence of cull dumps.

16. Seasons with heavy rainfall are most favorable for flea beetle development and subsequent tuber injury. Adequate moisture during September and October and the following May and June favors winter survival and spring emergence of the overwintered adults.

17. A comparison of tubers from plots of potatoes receiving five or six irrigations during the season showed almost three times as many larval blemishes as potatoes irrigated twice, and nearly eight times the number found on tubers from plots watered once.

18. The largest populations of flea beetles are found in early planted potato fields.

19. The type of food plant consumed by adult flea beetles markedly influenced oviposition and length of life. Potato foliage was the most

satisfactory food, egg production being highest and mortality lowest on such a diet. On the same basis tomato and wild tomato, <u>Solanum triflorum</u>, also were favorable adult foods. Buffalo bur, <u>Solanum rostratum</u>, although equally adequate for adult subsistence, proved inferior for egg production. Measured in terms of both oviposition and longevity the least satisfactory food plants were prairie ground cherry, <u>Physalis lanceolata</u>; field beans, <u>Phaseolus vulgaris</u>, marsh elder, <u>Iva xanthifolia</u>, and kochia, <u>Kochia scoparia</u>.

20. The substitution of potato foliage for less nutritious diets was followed in two or three days by increased egg production. A change from potato to foliage of other food plants resulted in decreased egg production. In one 60-day test significant fluctuations in egg deposition were recorded when, at 10-day intervals, diets of potato foliage were alternated with either marsh elder or buffalo bur.

21. In the field, larvae developed most readily and in largest numbers on potato roots and tubers. Considerably less development occurred on roots of tomato. Relatively few individuals matured on ground cherry, black nightshade, <u>Solanum nigrum</u>, buffalo bur and bean. No larval development was recorded from wild tomato, marsh elder or kochia.

22. Large numbers of first generation flea beetles develop on the volunteer growth in potato cull dumps.

23. The severity of tuber injury is influenced to a marked extent by date of planting, being much more acute in early fields.

24. Tuber flea beetle larvae are responsible for a portion of the low total yields obtained in early planted fields. Approximately 30 per cent of the stolons, or potential tuber-forming areas, were destroyed by the feeding

activities of the larvae.

25. Early plantings have a marked influence on the beetle population and injury in nearby late fields. It has been observed repeatedly that the more heavily infested late plantings have been located near early fields.

26. In a varietal susceptibility test involving eight varieties, the Triumph, most widely grown potato in western Nebraska, proved most resistant to larval injury.

27. The potato crop should be harvested as soon as possible to avoid late season injury. Larval blemishes, composed largely of "slivers" and "pimples," increased during September but there was practically no addition to the number of "worm tracks" during that period.

28. Dusts, properly applied, equalled sprays in effectiveness for the control of flea beetles in western Nebraska.

29. Among the sprays tested in the earlier experiments (1940-1943), zinc arsenite and basic copper arsenate proved best. Cryolite and Dutox (barium fluosilicate) were among the less effective materials.

30. Of the dusts tested in the earlier experiments, Dutox and cryolite, which were equally effective, ranked first.

31. In the 1944 field and insectary experiments, DDT in both spray and dust form was significantly better than all other treatments for controlling flea beetles.

32. DDT-sulfur dusts appeared a little more efficient than the DDT-pyrophyllite mixtures in 1945 tests. Over a period of 11 days a 1 per cent DDT-fused with sulfur dust remained more effective than a 3 per cent DDT-pyrophyllite dust. A 1 per cent DDT-pyrophyllite dust gave unsatisfactory control.

33. Good results were obtained with airplane applications of 3 per cent DDT dusts.

34. For effective control of flea beetles, late planted fields should be treated three or more times during the season. Single applications generally prove unsatisfactory.

35. Under typical late field conditions, the applications made in August are of greatest value in reducing flea beetle injury. Growers should continue the spray or dust program well into the month of August, or until the vines close the rows.

36. In a preliminary test, soil applications of DDT-pyrophyllite dusts significantly reduced the amount of larval injury to tubers.

37. The use of zinc arsenite sprays for the control of flea beetles usually was followed by significant increases in aphid populations.

38. Although some beneficial insect species were killed in DDT-treated potato fields, large scale tests indicated that this would have no appreciable effect on the insect problem as a whole. No increases of harmful insects were recorded following the use of DDT on potatoes.

39. The cultural practices effective as control measures for tuber flea beetles also aid in the control of most other pests of the potato in western Nebraska.

LITERATURE CITED

1. Anderson, L. D. A ten-year study of the life history and control of the potato flea beetle (Epitrix cucumeris Harris) in eastern Virginia. Ohio State Univ. Abst. Doctoral Diss. no. 38, p. 3-14. 1942.

2. ________ and Walker, H. G. The life history and control of the potato flea beetle, Epitrix cucumeris Harris. Jour. Econ. Ent. 27:102-106. 1934.

3. ________ and ________ Control of the potato flea beetle. Va. Truck Exp. Sta. Bul. 92. 1936.

4. Baker, W. Potato flea beetle. West. Wash. Agr. Exp. Sta. Bul. n.s. 10-W p. 12. October, 1928.

5. ________ Potato flea beetle project. West. Wash. Agr. Exp. Sta. Bul. n.s. 14-W p. 10. October, 1929.

6. Barrus, M. F. and Chupp, C. Potato diseases and their control. N. Y. (Cornell) Agr. Ext. Bul. 135. 1937.

7. ________ and Leiby, R. W. Spraying and dusting potatoes in up-state New York. N. Y. (Cornell) Agr. Ext. Bul. 518. 1942.

8. Besse, R. S. and Burtner, J. C. (compilers). Special agricultural investigations. Practical control still sought for flea beetle. Oreg. Agr. Exp. Sta. Bul. 130. 1938.

9. Breitenbecker, J. K. The relation of water to the behavior of the potato beetle in a desert. Carnegie Inst. Wash. Pub. 263:341-384. 1918.

10. Britton, W. E. Thirty-second report of Connecticut state entomologist 1932. Conn. Agr. Exp. Sta. Bul. 349:365-460. 1933.

11. Bruce, W. N. and Tauber, O. E. Trials with DDT on potatoes, cabbage, and squash. Jour. Econ. Ent. 38:439-441. 1945.

12. Cameron, A. E. Potato spraying and dusting in New Jersey, U. S. A. Bul. Ent. Res. 6:1-21. 1915.

13. Chamberlin, F. S. and Tenhet, J. N. The tobacco flea beetle in the southern cigar-wrapper district. U. S. Dept. Agr. Farmers' Bul. 1352. 1923.

14. Chittenden, F. H. Some insects injurious to garden and orchard crops. U. S. Dept. Agr. Div. of Ent. Bul. n.s. 19:80-90. 1899.

15. Cockerell, T. D. A. Observations on insects. N. Mex. Agr. Exp. Sta. Bul. 35. 1900.

16. Cooley, R. A. Ortho arsenite of zinc as an insecticide. Jour. Econ. Ent. 5:142-146. 1912.

17. Daniels, L. B. Potato flea beetle control. Colo. Agr. Exp. Sta. Bul. 400. 1933.

18. ________ Controlling Colorado potato pests. Colo. Agr. Exp. Sta. Bul. 437. 1937.

19. ________ Colorado potato pests. Colo. Agr. Exp. Sta. Bul. 465. 1941.

20. Dominick, C. B. Notes on the tobacco flea beetle, Epitrix parvula (F.). Jour. Econ. Ent. 32:495-498. 1939.

21. ________ and Wene, G. Notes on the hibernation of the tobacco flea beetle and on the parasite, Microctonus epitricis (Vier.). Jour. Econ. Ent. 34:395-396. 1941.

22. Douglass, J. R. Additional information on precipitation as a factor in the emergence of Epilachna corrupta Muls. from hibernation. Ecology 14:286-297. 1933.

23. Dustan, A. G. Insects attacking the potato. Canada Dept. Agr. Pub. 505. 1936.

24. Eyer, J. R. and Enzie, J. V. Dusting and spraying for the control of insect pests of the Irish potato. N. Mex. Agr. Exp. Sta. Bul. 266. 1939.

25. Fitch, A. Eleventh report on noxious, beneficial and other insects of the state of New York. p. 52-62. Albany, Van Benthuysen and Sons. 1867.

26. Fulton, H. G. and Glendenning, R. The tuber flea beetle in British Columbia and its control. Dominion Entomological Laboratory (Agassiz, B. C.) Division of Entomology Processed Publication no. 48. 1946.

27. Gentner, L. G. The black flea beetles of the genus Epitrix commonly identified as cucumeris (Harris) (Coleoptera: Chrysomelidae). Wash. Ent. Soc. Proc. 46:137-149. 1944.

28. Goodhue, L. D., Smith, F. F. and Ditman, L. P. DDT in aerosol form to control insects on vegetables. Jour. Econ. Ent. 38:179-182. 1945.

29. Goss, R. W. Infection experiments with spindle tuber and unmottled curly dwarf of the potato. Nebr. Agr. Exp. Sta. Bul. 53. 1931.

30. Granovsky, A. A. Test of DDT for the control of potato insects. Jour. Econ. Ent. 37:493-499. 1944.

31. Gui, H. L. Potato flea beetles and their control. Ohio Agr. Exp. Sta. Bul. 595. 1938.

32. Gyrisko, G. G., Jodka, J. F. T. and Rawlins, W. A. DDT to control potato insects. Jour. Econ. Ent. 38:169-173. 1945.

33. Hanson, A. J. The potato flea beetles, Epitrix cucumeris Harris, Epitrix subcrinita Leconte. Wash. Agr. Exp. Sta. Bul. 280. 1933.

34. Harris, T. W. Catalogue of insects of Massachusetts. 1835. Original not seen; cited by Johannsen (47) in Maine Agr. Exp. Sta. Bul. 211:38. 1913.

35. ________ A report on the insects of Massachusetts injurious to vegetation. p. 102-103. Cambridge, Folsom, Wells and Thurston. 1841.

36. ________ Insects on the potato-vine. Jour. of Agr. 1:103. 1851. Original not seen; cited by Johannsen (47) in Maine Agr. Exp. Sta. Bul. 211:38. 1913.

37. ________ A treatise on some of the insects of New England which are injurious to vegetation. 2d ed. p. 113. Boston, White and Potter. 1852.

38. Harvey, F. L. Botanist's and entomologist's report. Maine Agr. Exp. Sta. Ann. Rept. 1895.

39. Hill, R. E. Effects of DDT and other insecticides on several species of potato insects. Nebr. Agr. Exp. Sta. Res. Bul. 138. 1945.

40. ________ and Tate, H. D. Life history and habits of the potato flea beetle in western Nebraska. Jour. Econ. Ent. 35:879-884. 1942.

41. ________ and ________ Increases in aphid populations on potato plants sprayed with zinc arsenite in western Nebraska. Jour. Econ. Ent. 36:63-66. 1943.

42. ________ and ________ Potato flea beetle control in western Nebraska. Nebr. Agr. Exp. Sta. Bul. 361. 1944.

43. Hoerner, J. L. and Gillette, C. P. The potato flea beetle. Colo. Agr. Exp. Sta. Bul. 337. 1928.

44. Hodson, A. C. Some aspects of the role of water in insect hibernation. Ecol. Monog. v.7, no.2, p.271-315. 1937.

45. Huckett, H. C. Planting dates as an aid to potato insect control on Long Island. N. Y. (Geneva) Agr. Exp. Sta. Bul. 652. 1935.

46. Jewett, H. H. Potato flea beetles. Ky. Agr. Exp. Sta. Bul. 297:283-301. 1930.

47. Johannsen, O. A. Potato flea-beetle. Maine Agr. Exp. Sta. Bul. 211. 1913.

48. ________ Eggs of the potato flea beetle, Epitrix cucumeris Harris. Jour. Econ. Ent. 14:511-512. 1921.

49. Johnson, S. A. Fall handling of potatoes to lessen injuries from insects and fungi. The potato flea beetle. Colo. Agr. Exp. Sta. Press Bul. 23. September, 1904.

50. ________ Potato insects. Colo. Agr. Exp. Sta. Bul. 175:42-45. 1910.

51. Jones, E. W. Biological studies of two potato flea beetles in eastern Washington. Jour. Econ. Ent. 37:9-12. 1944.

52. Jones, L. R. Spraying potatoes. Vt. Agr. Exp. Sta. Bul. 40. 1894.

53. Knowlton, G. F. Some potato insects of Utah. Utah Acad. Sci., Arts and Letters Proc. 14:154. 1937.

54. Landis, B. J. Potato flea beetles and their control in eastern Washington. Wash. Agr. Exp. Sta. V. Cir. 9. 1943.

55. Leach, J. G. Insect transmission of plant diseases. p. 314. McGraw-Hill Book Co., Inc. 1940.

56. Lodeman, E. G. Insects. N. Y. (Cornell) Agr. Exp. Sta. Bul. 113, pt.2. 1896.

57. MacMillan, H. G. and Schaal, L. A. A pathological feature of flea-beetle injury of potato tubers. Jour. Agr. Res. 39:807-815. 1929.

58. Martin, W. H. Dissemination of Septoria lycopersici Speg. by insects and pickers. Phytopathology 8:365-372. 1918.

59. Metcalf, C. L. A mechanical measure for controlling flea beetle (Epitrix fuscula). Jour. Econ. Ent. 8:240-241. 1915.

60. Mills, H. B., Callenbach, J. A. and Reinhardt, J. F. Montana insect pests, 1943 and 1944. Thirtieth report of the state entomologist. Mont. Agr. Exp. Sta. Bul. 425. 1945.

61. Muesebeck, C. F. W. Common names of insects approved by the American Association of Economic Entomologists. Jour. Econ. Ent. 39:427-448. 1946.

62. Rawlins, W. A. Studies of potato tuber defects in western New York. Jour. Econ. Ent. 25:649-651. 1932.

63. ________ Potato insect investigations in 1939. Amer. Potato Jour. 17:135-139. 1940.

64. Riedl, W. A. and Harrison, L. R. The control of psyllids and flea beetles on potatoes. Wyo. Agr. Exp. Sta. Bul. 271. 1945.

65. Riley, C. V. The cucumber flea beetle. First annual report on noxious, beneficial and other insects of the state of Missouri, 1868:101. Jefferson City, Ellwood Kirby. 1869.

66. Schaal, L. A. Relation of the potato flea beetle to common scab of potatoes. Jour. Agr. Res. 49:251-258. 1934.

67. Sleesman, J. P. Variations in potato varieties to flea beetle attack. Ohio Agr. Exp. Sta. Ann. Rept. Bul. 579:52-53. 1937.

68. ________, Gui, H. L. and Wilson, J. D. DDT and other new materials for spraying potatoes. Amer. Potato Jour. 22:242-249. 1945.

69. Smith, F. F., Ditman, L. P. and Goodhue, L. D. Experiments with aerosols against some pests of truck crops. Jour. Econ. Ent. 38:189-196. 1945.

70. Stewart, F. C. The cucumber flea-beetle as the cause of "pimply" potatoes. N. Y. (Geneva) Agr. Exp. Sta. Bul. n.s. 113:311-317. 1896.

71. Stewart, R. P. A modification of the flea beetle trap. Roy. Hort. Soc. Jour. 68:275. 1943.

72. Swenk, M. H. and Tate, H. D. The potato flea beetle and the potato psyllid in Nebraska. Nebr. Agr. Exp. Sta. Bul. 327. 1940.

73. ________ and Wilcox, E. M. Spraying potatoes for insects and diseases. Nebr. Agr. Col. Ext. Emergency Bul. 10. 1917.

74. Turner, N. Biology and control of the potato flea beetle. Thirty-ninth report of the state entomologist 1939. Conn. Agr. Exp. Sta. Bul. 434:277-283. 1940.

75. Webster, R. L. Potato insects. Iowa Agr. Exp. Sta. Bul. 155:367-375. 1915.

76. ________ Injury and distribution of potato flea beetle in Washington, _Epitrix cucumeris_ Harris, _Epitrix subcrinita_ Leconte. Jour. Econ. Ent. 25:976-980. 1932.

77. ________ and Baker, W. Potato flea-beetles in Washington, _Epitrix subcrinita_ Leconte: _Epitrix cucumeris_ Harris. Jour. Econ. Ent. 22:897-900. 1929.

78. ________, ________ and Hanson, A. J. Potato flea beetles in Washington. Wash. Agr. Exp. Sta. Bul. 261. 1932.

79. ________, Landis, B. J. and Getzendaner, C. W. Biology and control of the potato flea beetle in eastern Washington. Wash. Agr. Exp. Sta. Bul. 410:48-49. 1941.

80. Wilson, G. F. A flea beetle trap. Roy. Hort. Soc. Jour. 68:106-107. 1943.

81. Wolfenbarger, D. O. Some effects on potato flea-beetle (_Epitrix cucumeris_ Harris) injuries and yields by spraying. Jour. Econ. Ent. 27:118-120. 1934.

82. Yothers, M. A. Potato insects. Wash. Agr. Exp. Sta. Pop. Bul. 106: 114-116. 1917.

ACKNOWLEDGMENTS

These experiments were conducted as part of a project on potato insect control at the Nebraska Agricultural Experiment Station. An expression of gratitude is due Dean W. W. Burr, Director of the Experiment Station, and Dr. H. D. Tate and Dr. Ephriam Hixson, past and present Chairman, respectively, of the Department of Entomology, for permission to use these data. Mention also should be made of Dr. Tate's valuable counsel during the first six years of the project.

The author is indebted to his colleagues in the Department of Entomology, Mr. O. S. Bare and Dr. C. A. Sooter, both of whom aided with some of the field work, and Dr. M. H. Muma for the drawings of the flea beetle life stages. Thanks are extended to Mr. Lionel Harris, Superintendent, Scotts Bluff Substation, for his ready cooperation in providing laboratory and experimental facilities. The summer assistance of entomology students, Messrs. Edward Klostermeyer, Stanley Leidke and Jack Lomax, and the help and cooperation received from innumerable other persons is appreciated.

Sincerely appreciated are the many courtesies and helpful suggestions which Dr. C. J. Drake extended to the author during his course of study at Iowa State College. The friendly advice of many other members of the Department of Zoology and Entomology also is gratefully acknowledged. Finally, appreciative recognition is due the writer's wife, Norene J. Hill, for the competent and conscientious typing of the manuscript.